REPORT

OF THE

FIFTY-FIFTH MEETING

OF THE

BRITISH ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE;

HELD AT

ABERDEEN IN SEPTEMBER 1885.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1886.

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OBJECTS.

The Association contemplates no interference with the ground occupied by other institutions. Its objects are:—To give a stronger impulse and a more systematic direction to scientific inquiry,—to promote the intercourse of those who cultivate Science in different parts of the British Empire, with one another and with foreign philosophers,—to obtain a more general attention to the objects of Science, and a removal of any disadvantages of a public kind which impede its progress.

RULES.

Admission of Members and Associates.

All persons who have attended the first Meeting shall be entitled to become Members of the Association, upon subscribing an obligation to conform to its Rules.

The Fellows and Members of Chartered Literary and Philosophical Societies publishing Transactions, in the British Empire, shall be entitled, in like manner, to become Members of the Association.

The Officers and Members of the Councils, or Managing Committees, of Philosophical Institutions shall be entitled, in like manner, to become Members of the Association.

All Members of a Philosophical Institution recommended by its Council or Managing Committee shall be entitled, in like manner, to become Members of the Association.

Persons not belonging to such Institutions shall be elected by the General Committee or Council, to become Life Members of the Association, Annual Subscribers, or Associates for the year, subject to the approval of a General Meeting.

Compositions, Subscriptions, and Privileges.

Life Members shall pay, on admission, the sum of Ten Pounds. They shall receive *gratuitously* the Reports of the Association which may be published after the date of such payment. They are eligible to all the offices of the Association.

Annual Subscribers shall pay, on admission, the sum of Two Pounds, and in each following year the sum of One Pound. They shall receive *gratuitously* the Reports of the Association for the year of their admission and for the years in which they continue to pay *without intermission* their Annual Subscription. By omitting to pay this subscription in any particular year, Members of this class (Annual Subscribers) *lose for that and*

all future years the privilege of receiving the volumes of the Association *gratis:* but they may resume their Membership and other privileges at any subsequent Meeting of the Association, paying on each such occasion the sum of One Pound. They are eligible to all the Offices of the Association.

ASSOCIATES for the year shall pay on admission the sum of One Pound. They shall not receive *gratuitously* the Reports of the Association, nor be eligible to serve on Committees, or to hold any office.

The Association consists of the following classes:—

1. Life Members admitted from 1831 to 1845 inclusive, who have paid on admission Five Pounds as a composition.
2. Life Members who in 1846, or in subsequent years, have paid on admission Ten Pounds as a composition.
3. Annual Members admitted from 1831 to 1839 inclusive, subject to the payment of One Pound annually. [May resume their Membership after intermission of Annual Payment.]
4. Annual Members admitted in any year since 1839, subject to the payment of Two Pounds for the first year, and One Pound in each following year. [May resume their Membership after intermission of Annual Payment.]
5. Associates for the year, subject to the payment of One Pound.
6. Corresponding Members nominated by the Council.

And the Members and Associates will be entitled to receive the annual volume of Reports, *gratis*, or to *purchase* it at reduced (or Members') price, according to the following specification, viz.:—

1. *Gratis.*—Old Life Members who have paid Five Pounds as a composition for Annual Payments, and previous to 1845 a further sum of Two Pounds as a Book Subscription, or, since 1845, a further sum of Five Pounds.

   New Life Members who have paid Ten Pounds as a composition.

   Annual Members *who have not intermitted* their Annual Subscription.
2. *At reduced or Members' Prices*, viz. two-thirds of the Publication Price.—Old Life Members who have paid Five Pounds as a composition for Annual Payments, but no further sum as a Book Subscription.

   Annual Members who have intermitted their Annual Subscription.

   Associates for the year. [Privilege confined to the volume for that year only.]
3. Members may purchase (for the purpose of completing their sets) any of the volumes of the Reports of the Association up to 1874, *of which more than* 15 *copies remain*, at 2*s*. 6*d*. per volume.[1]

Application to be made at the Office of the Association, 22 Albemarle Street, London, W.

Volumes not claimed within two years of the date of publication can only be issued by direction of the Council.

Subscriptions shall be received by the Treasurer or Secretaries.

[1] A few complete sets, 1831 to 1874, are on sale, £10 the set.

Meetings.

The Association shall meet annually, for one week, or longer. The place of each Meeting shall be appointed by the General Committee two years in advance; and the arrangements for it shall be entrusted to the Officers of the Association.

General Committee.

The General Committee shall sit during the week of the Meeting, or longer, to transact the business of the Association. It shall consist of the following persons:—

CLASS A. PERMANENT MEMBERS.

1. Members of the Council, Presidents of the Association, and Presidents of Sections for the present and preceding years, with Authors of Reports in the Transactions of the Association.

2. Members who by the publication of Works or Papers have furthered the advancement of those subjects which are taken into consideration at the Sectional Meetings of the Association. *With a view of submitting new claims under this Rule to the decision of the Council, they must be sent to the Secretary at least one month before the Meeting of the Association. The decision of the Council on the claims of any Member of the Association to be placed on the list of the General Committee to be final.*

CLASS B. TEMPORARY MEMBERS.[1]

1. Delegates nominated by the Corresponding Societies under the conditions hereinafter explained. *Claims under this Rule to be sent to the Secretary before the opening of the Meeting.*

2. Office-bearers for the time being, or delegates, altogether not exceeding three, from Scientific Institutions established in the place of Meeting. *Claims under this Rule to be approved by the Local Secretaries before the opening of the Meeting.*

3. Foreigners and other individuals whose assistance is desired, and who are specially nominated in writing, for the Meeting of the year, by the President and General Secretaries.

4. Vice-Presidents and Secretaries of Sections.

Organizing Sectional Committees.[2]

The Presidents, Vice-Presidents, and Secretaries of the several Sections are nominated by the Council, and have power to act until their names are submitted to the General Committee for election.

From the time of their nomination they constitute Organizing Committees for the purpose of obtaining information upon the Memoirs and Reports likely to be submitted to the Sections,[3] and of preparing Reports thereon, and on the order in which it is desirable that they should be read, to be presented to the Committees of the Sections at their first

[1] Revised by the General Committee, 1884.

[2] Passed by the General Committee, Edinburgh, 1871.

[3] *Notice to Contributors of Memoirs.*—Authors are reminded that, under an arrangement dating from 1871, the acceptance of Memoirs, and the days on which they are to be read, are now as far as possible determined by Organizing Committees for the several Sections *before the beginning of the Meeting.* It has therefore become necessary, in order to give an opportunity to the Committees of doing justice to the several Communications, that each Author should prepare an Abstract of his Memoir, of a length suitable for insertion in the published Transactions of the Association, and that he should send it, together with the original Memoir, by book-post, on or

meeting. The Sectional Presidents of former years are *ex officio* members of the Organizing Sectional Committees.[1]

An Organizing Committee may also hold such preliminary meetings as the President of the Committee thinks expedient, but shall, under any circumstances, meet on the first Wednesday of the Annual Meeting, at 11 A.M., to nominate the first members of the Sectional Committee, if they shall consider it expedient to do so, and to settle the terms of their report to the General Committee, after which their functions as an Organizing Committee shall cease.[2]

Constitution of the Sectional Committees.[3]

On the first day of the Annual Meeting, the President, Vice-Presidents, and Secretaries of each Section having been appointed by the General Committee, these Officers, and those previous Presidents and Vice-Presidents of the Section who may desire to attend, are to meet, at 2 P.M., in their Committee Rooms, and enlarge the Sectional Committees by selecting individuals from among the Members (not Associates) present at the Meeting whose assistance they may particularly desire. The Sectional Committees thus constituted shall have power to add to their number from day to day.

The List thus formed is to be entered daily in the Sectional Minute-Book, and a copy forwarded without delay to the Printer, who is charged with publishing the same before 8 A.M. on the next day in the Journal of the Sectional Proceedings.

Business of the Sectional Committees.

Committee Meetings are to be held on the Wednesday at 2 P.M., on the following Thursday, Friday, Saturday,[4] Monday, and Tuesday, from 10 to 11 A.M., punctually, for the objects stated in the Rules of the Association, and specified below.

The business is to be conducted in the following manner :—

1. The President shall call on the Secretary to read the minutes of the previous Meeting of the Committee.
2. No paper shall be read until it has been formally accepted by the Committee of the Section, and entered on the minutes accordingly.
3. Papers which have been reported on unfavourably by the Organizing Committees shall not be brought before the Sectional Committees.[5]

At the first meeting, one of the Secretaries will read the Minutes of last year's proceedings, as recorded in the Minute-Book, and the Synopsis

before........................., addressed thus—'General Secretaries, British Association, 22 Albemarle Street, London, W. For Section ....' If it should be inconvenient to the Author that his paper should be read on any particular days, he is requested to send information thereof to the Secretaries in a separate note. Authors who send in their MSS. three complete weeks before the Meeting, and whose papers are accepted, will be furnished, before the Meeting, with printed copies of their Reports and Abstracts. No Report, Paper, or Abstract can be inserted in the Annual Volume unless it is handed either to the Recorder of the Section or to the Secretary, *before the conclusion of the Meeting.*

[1] Added by the General Committee, Sheffield, 1879.

[2] Revised by the General Committee, Swansea, 1880.

[3] Passed by the General Committee, Edinburgh, 1871.

[4] The meeting on Saturday was made optional by the General Committee at Southport, 1883.

[5] These rules were adopted by the General Committee, Plymouth, 1877.

of Recommendations adopted at the last Meeting of the Association and printed in the last volume of the Transactions. He will next proceed to read the Report of the Organizing Committee.[1] The list of Communications to be read on Thursday shall be then arranged, and the general distribution of business throughout the week shall be provisionally appointed. At the close of the Committee Meeting the Secretaries shall forward to the Printer a List of the Papers appointed to be read. The Printer is charged with publishing the same before 8 A.M. on Thursday in the Journal.

On the second day of the Annual Meeting, and the following days, the Secretaries are to correct, on a copy of the Journal, the list of papers which have been read on that day, to add to it a list of those appointed to be read on the next day, and to send this copy of the Journal as early in the day as possible to the Printer, who is charged with printing the same before 8 A.M. next morning in the Journal. It is necessary that one of the Secretaries of each Section (generally the Recorder) should call at the Printing Office and revise the proof each evening.

Minutes of the proceedings of every Committee are to be entered daily in the Minute-Book, which should be confirmed at the next meeting of the Committee.

Lists of the Reports and Memoirs read in the Sections are to be entered in the Minute-Book daily, which, with *all Memoirs and Copies or Abstracts of Memoirs furnished by Authors, are to be forwarded, at the close of the Sectional Meetings*, to the Secretary.

The Vice-Presidents and Secretaries of Sections become *ex officio* temporary Members of the General Committee (*vide* p. xxix), and will receive, on application to the Treasurer in the Reception Room, Tickets entitling them to attend its Meetings.

The Committees will take into consideration any suggestions which may be offered by their Members for the advancement of Science. They are specially requested to review the recommendations adopted at preceding Meetings, as published in the volumes of the Association and the communications made to the Sections at this Meeting, for the purposes of selecting definite points of research to which individual or combined exertion may be usefully directed, and branches of knowledge on the state and progress of which Reports are wanted; to name individuals or Committees for the execution of such Reports or researches; and to state whether, and to what degree, these objects may be usefully advanced by the appropriation of the funds of the Association, by application to Government, Philosophical Institutions, or Local Authorities.

In case of appointment of Committees for special objects of Science, it is expedient that *all Members of the Committee should be named, and one of them appointed to act as Secretary, for insuring attention to business.*

Committees have power to add to their number persons whose assistance they may require.

The recommendations adopted by the Committees of Sections are to be registered in the Forms furnished to their Secretaries, and one Copy of each is to be forwarded, without delay, to the Secretary for presentation to the Committee of Recommendations. *Unless this be done, the Recommendations cannot receive the sanction of the Association.*

N.B.—Recommendations which may originate in any one of the Sections must *first be sanctioned by the Committee of that Section* before they

[1] This and the following sentence were added by the General Committee, 1871.

can be referred to the Committee of Recommendations or confirmed by the General Committee.

The Committees of the Sections shall ascertain whether a Report has been made by every Committee appointed at the previous Meeting to whom a sum of money has been granted, and shall report to the Committee of Recommendations in every case where no such Report has been received.[1]

Notices regarding Grants of Money.

Committees and individuals, to whom grants of money have been entrusted by the Association for the prosecution of particular researches in science, are required to present to each following Meeting of the Association a Report of the progress which has been made; and the Individual or the Member first named of a Committee to whom a money grant has been made must (previously to the next Meeting of the Association) forward to the General Secretaries or Treasurer a statement of the sums which have been expended, and the balance which remains disposable on each grant.

Grants of money sanctioned at any one Meeting of the Association expire *a week before* the opening of the ensuing Meeting; nor is the Treasurer authorized, after that date, to allow any claims on account of such grants, unless they be renewed in the original or a modified form by the General Committee.

No Committee shall raise money in the name or under the auspices of the British Association without special permission from the General Committee to do so; and no money so raised shall be expended except in accordance with the rules of the Association.

In each Committee, the Member first named is the only person entitled to call on the Treasurer, Professor A. W. Williamson, University College, London, W.C., for such portion of the sums granted as may from time to time be required.

In grants of money to Committees, the Association does not contemplate the payment of personal expenses to the members.

In all cases where additional grants of money are made for the continuation of Researches at the cost of the Association, the sum named is deemed to include, as a part of the amount, whatever balance may remain unpaid on the former grant for the same object.

All Instruments, Papers, Drawings, and other property of the Association are to be deposited at the Office of the Association, 22 Albemarle Street, Piccadilly, London, W., when not employed in carrying on scientific inquiries for the Association.

Business of the Sections.

The Meeting Room of each Section is opened for conversation from 10 to 11 daily. *The Section Rooms and approaches thereto can be used for no notices, exhibitions, or other purposes than those of the Association.*

At 11 precisely the Chair will be taken,[2] and the reading of communications, in the order previously made public, commenced. At 3 P.M. the Sections will close.

Sections may, by the desire of the Committees, divide themselves into Departments, as often as the number and nature of the communications delivered in may render such divisions desirable.

[1] Passed by the General Committee at Sheffield, 1879.

[2] The meeting on Saturday may begin, if desired by the Committee, at any time not earlier than 10 or later than 11. Passed by the General Committee at Southport, 1883.

A Report presented to the Association, and read to the Section which originally called for it, may be read in another Section, at the request of the Officers of that Section, with the consent of the Author.

Duties of the Doorkeepers.

1.—To remain constantly at the Doors of the Rooms to which they are appointed during the whole time for which they are engaged.
2.—To require of every person desirous of entering the Rooms the exhibition of a Member's, Associate's, or Lady's Ticket, or Reporter's Ticket, signed by the Treasurer, or a Special Ticket signed by the Secretary.
3.—Persons unprovided with any of these Tickets can only be admitted to any particular Room by order of the Secretary in that Room.

No person is exempt from these Rules, except those Officers of the Association whose names are printed in the programme, p. 1.

Duties of the Messengers.

To remain constantly at the Rooms to which they are appointed during the whole time for which they are engaged, except when employed on messages by one of the Officers directing these Rooms.

Committee of Recommendations.

The General Committee shall appoint at each Meeting a Committee, which shall receive and consider the Recommendations of the Sectional Committees, and report to the General Committee the measures which they would advise to be adopted for the advancement of Science.

All Recommendations of Grants of Money, Requests for Special Researches, and Reports on Scientific Subjects shall be submitted to the Committee of Recommendations, and not taken into consideration by the General Committee unless previously recommended by the Committee of Recommendations.

Corresponding Societies.[1]

(1.) Any Society is eligible to be placed on the List of Corresponding Societies of the Association which undertakes local scientific investigations, and publishes notices of the results.

(2.) Applications may be made by any Society to be placed on the List of Corresponding Societies. Application must be addressed to the Secretary on or before the 1st of June preceding the Annual Meeting at which it is intended they should be considered, and must be accompanied by specimens of the publications of the results of the local scientific investigations recently undertaken by the Society.

(3.) A Corresponding Societies Committee shall be annually nominated by the Council and appointed by the General Committee for the purpose of considering these applications, as well as for that of keeping themselves generally informed of the annual work of the Corresponding Societies, and of superintending the preparation of a list of the papers published by them. This Committee shall make an annual report to the General Committee, and shall suggest such additions or changes in the List of Corresponding Societies as they may think desirable.

(4.) Every Corresponding Society shall return each year, on or before the 1st of June, to the Secretary of the Association, a schedule,

[1] Passed by the General Committee, 1884.

properly filled up, which will be issued by the Secretary of the Association, and which will contain a request for such particulars with regard to the Society as may be required for the information of the Corresponding Societies Committee.

(5.) There shall be inserted in the Annual Report of the Association a list, in an abbreviated form, of the papers published by the Corresponding Societies during the past twelve months which contain the results of the local scientific work conducted by them; those papers only being included which refer to subjects coming under the cognizance of one or other of the various Sections of the Association.

(6.) A Corresponding Society shall have the right to nominate any one of its members, who is also a Member of the Association, as its delegate to the Annual Meeting of the Association, who shall be for the time a Member of the General Committee.

Conference of Delegates of Corresponding Societies.

(7.) The Delegates of the various Corresponding Societies shall constitute a Conference, of which the Chairman, Vice-Chairmen, and Secretaries shall be annually nominated by the Council, and appointed by the General Committee, and of which the members of the Corresponding Societies Committee shall be *ex officio* members.

(8.) The Conference of Delegates shall be summoned by the Secretaries to hold one or more meetings during each Annual Meeting of the Association, and shall be empowered to invite any Member or Associate to take part in the meetings.

(9.) The Secretaries of each Section shall be instructed to transmit to the Secretaries of the Conference of Delegates copies of any recommendations forwarded by the Presidents of Sections to the Committee of Recommendations bearing upon matters in which the co-operation of Corresponding Societies is desired; and the Secretaries of the Conference of Delegates shall invite the authors of these recommendations to attend the meetings of the Conference and give verbal explanations of their objects and of the precise way in which they would desire to have them carried into effect.

(10.) It will be the duty of the Delegates to make themselves familiar with the purport of the several recommendations brought before the Conference, in order that they and others who take part in the meetings may be able to bring those recommendations clearly and favourably before their respective Societies. The Conference may also discuss propositions bearing on the promotion of more systematic observation and plans of operation, and of greater uniformity in the mode of publishing results.

Local Committees.

Local Committees shall be formed by the Officers of the Association to assist in making arrangements for the Meetings.

Local Committees shall have the power of adding to their numbers those Members of the Association whose assistance they may desire.

Officers.

A President, two or more Vice-Presidents, one or more Secretaries, and a Treasurer shall be annually appointed by the General Committee.

Council.

In the intervals of the Meetings, the affairs of the Association shall be managed by a Council appointed by the General Committee. The Council may also assemble for the despatch of business during the week of the Meeting.

Papers and Communications.

The Author of any paper or communication shall be at liberty to reserve his right of property therein.

Accounts.

The Accounts of the Association shall be audited annually, by Auditors appointed by the General Committee.

Table showing the Places and Times of Meeting of the British Association, with Presidents, Vice-Presidents, and Local Secretaries, from its Commencement.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The EARL FITZWILLIAM, D.C.L., F.R.S., F.G.S., &c. YORK, September 27, 1831.	Rev. W. Vernon Harcourt, M.A., F.R.S., F.G.S.	William Gray, jun., Esq., F.G.S. Professor Phillips, M.A., F.R.S., F.G.S.
The REV. W. BUCKLAND, D.D., F.R.S., F.G.S., &c. OXFORD, June 19, 1832.	Sir David Brewster, F.R.S. L. & E., &c. Rev. W. Whewell, F.R.S., Pres. Geol. Soc.	Professor Daubeny, M.D., F.R.S., &c. Rev. Professor Powell, M.A., F.R.S., &c.
The REV. ADAM SEDGWICK, M.A., V.P.R.S., V.P.G.S. CAMBRIDGE, June 25, 1833.	G. B. Airy, Esq., F.R.S., Astronomer Royal, &c. John Dalton, Esq., D.C.L., F.R.S.	Rev. Professor Henslow, M.A., F.L.S., F.G.S. Rev. W. Whewell, F.R.S.
SIR T. MACDOUGALL BRISBANE, K.C.B., D.C.L., F.R.S. L. & E. EDINBURGH, September 8, 1834.	Sir David Brewster, F.R.S., &c. Rev. T. R. Robinson, D.D.	Professor Forbes, F.R.S. L. & E., &c. Sir John Robinson, Sec. R.S.E.
The REV. PROVOST LLOYD, LL.D. DUBLIN, August 10, 1835.	Viscount Oxmantown, F.R.S., F.R.A.S. Rev. W. Whewell, F.R.S., &c.	Sir W. R. Hamilton, Astron. Royal of Ireland, &c. Rev. Professor Lloyd, F.R.S.
The MARQUIS OF LANSDOWNE, D.C.L., F.R.S., &c. BRISTOL, August 22, 1836.	The Marquis of Northampton, F.R.S. Rev. W. D. Conybeare, F.R.S., F.G.S. J. C. Prichard, Esq., M.D., F.R.S.	Professor Daubeny, M.D., F.R.S., &c. V. F. Hovenden, Esq.
The EARL OF BURLINGTON, F.R.S., F.G.S., Chancellor of the University of London LIVERPOOL, September 11, 1837.	The Bishop of Norwich, P.L.S., F.G.S. John Dalton, Esq., D.C.L., F.R.S. Sir Philip de Grey Egerton, Bart., F.R.S., F.G.S. Rev. W. Whewell, F.R.S.	Professor Traill, M.D. Wm. Wallace Currie, Esq Joseph N. Walker, Esq., Pres. Royal Institution, Liverpool.
The DUKE OF NORTHUMBERLAND, F.R.S., F.G.S., &c. NEWCASTLE-ON-TYNE, August 20, 1838.	The Bishop of Durham, F.R.S., F.S.A. The Rev. W. Vernon Harcourt, F.R.S., &c. Prideaux John Selby, Esq., F.R.S.E.	John Adamson, Esq., F.L.S., &c. Wm. Hutton, Esq., F.G.S. Professor Johnston, M.A., F.R.S.
The REV. W. VERNON HARCOURT, M.A., F.R.S., &c. BIRMINGHAM, August 26, 1839.	The Marquis of Northampton. The Earl of Dartmouth The Rev. T. R. Robinson, D.D. John Corrie, Esq., F.R.S. The Very Rev. Principal Macfarlane	George Barker, Esq., F.R.S. Peyton Blakiston, Esq., M.D. Joseph Hodgson, Esq., F.R.S. Follett Osler, Esq.
The MARQUIS OF BREADALBANE, F.R.S. GLASGOW, September 17, 1840.	Major-General Lord Greenock, F.R.S.E. Sir David Brewster, F.R.S. Sir T. M. Brisbane, Bart., F.R.S. The Earl of Mount-Edgcumbe	Andrew Liddell, Esq. Rev. J. P. Nicol, LL.D. John Strang, Esq.
The REV. PROFESSOR WHEWELL, F.R.S., &c. PLYMOUTH, July 29, 1841.	The Earl of Morley. Lord Eliot, M.P. Sir C. Lemon, Bart. Sir T. D. Acland, Bart.	W. Snow Harris, Esq., F.R.S. Col. Hamilton Smith, F.L.S. Robert Were Fox, Esq. Richard Taylor, jun., Esq.
The LORD FRANCIS EGERTON, F.G.S. MANCHESTER, June 23, 1842.	John Dalton, Esq., D.C.L., F.R.S. Hon. and Rev. W. Herbert, F.L.S., &c. Rev. A. Sedgwick, M.A., F.R.S. W. C. Henry, Esq., M.D., F.R.S. Sir Benjamin Heywood, Bart.	Peter Clare, Esq., F.R.A.S. W. Fleming, Esq., M.D. James Heywood, Esq., F.R.S.
The EARL OF ROSSE, F.R.S. CORK, August 17, 1843.	The Earl of Listowel. Viscount Adare Sir W. R. Hamilton, Pres. R.I.A. Rev. T. R. Robinson, D.D.	Professor John Stevelly, M.A. Rev. Jos. Carson, F.T.C. Dublin. William Kelcher, Esq. Wm. Clear, Esq.
The REV. G. PEACOCK, D.D. (Dean of Ely), F.R.S. YORK, September 26, 1844.	Earl Fitzwilliam, F.R.S. Viscount Morpeth, F.G.S. The Hon. John Stuart Wortley, M.P. Sir David Brewster, K.H., F.R.S. Michael Faraday, Esq., D.C.L., F.R.S. Rev. W. V. Harcourt, F.R.S.	William Hatfeild, Esq., F.G.S. Thomas Meynell, Esq., F.L.S. Rev. W. Scoresby, LL.D., F.R.S. William West, Esq.
SIR JOHN F. W. HERSCHEL, Bart., F.R.S., &c. CAMBRIDGE, June 19, 1845.	The Earl of Hardwicke. The Bishop of Norwich Rev. J. Graham, D.D. Rev. G. Ainslie, D.D. G. B. Airy, Esq., M.A., D.C.L., F.R.S.	William Hopkins, Esq., M.A., F.R.S Professor Ansted, M.A., F.R.S.

SIR RODERICK IMPEY MURCHISON, G.C.St.S., F.R.S. SOUTHAMPTON, September 10, 1846.	The Marquis of Winchester. The Earl of Yarborough, D.C.L. Lord Ashburton, D.C.L. Viscount Palmerston, M.P. Right Hon. Charles Shaw Lefevre, M.P. Sir George T. Staunton, Bart., M.P., D.C.L., F.R.S. The Lord Bishop of Oxford, F.R.S. Professor Owen, M.D., F.R.S. The Rev. Professor Powell, F.R.S.	Henry Clark, Esq., M.D. T. H. C. Moody, Esq.
SIR ROBERT HARRY INGLIS, Bart., D.C.L., F.R.S., M.P. for the University of Oxford OXFORD, June 23, 1847.	The Earl of Rosse, F.R.S. The Lord Bishop of Oxford, F.R.S. The Vice-Chancellor of the University Thomas G. Bucknall Estcourt, Esq., D.C.L., M.P. for the University of Oxford. Very Rev. the Dean of Westminster, D.D., F.R.S. Professor Daubeny, M.D., F.R.S. The Rev. Prof. Powell, M.A., F.R.S.	Rev. Robert Walker, M.A., F.R.S. H. Wentworth Acland, Esq., B.M.
The MARQUIS OF NORTHAMPTON, President of the Royal Society, &c. SWANSEA, August 9, 1848.	The Marquis of Bute, K.T. Viscount Adare, F.R.S. Sir H. T. De la Beche, F.R.S., Pres. G.S. The Very Rev. the Dean of Llandaff, F.R.S. Lewis W. Dillwyn, Esq., F.R.S. W. R. Grove, Esq., F.R.S. J. H. Vivian, Esq., M.P., F.R.S. The Lord Bishop of St. David's	Matthew Moggridge, Esq. D. Nicol, Esq., M.D.
The REV. T. R. ROBINSON, D.D., M.R.I.A., F.R.A.S. BIRMINGHAM, September 12, 1849.	The Earl of Harrowby. The Lord Wrottesley, F.R.S. The Right Hon. Sir Robert Peel, Bart., M.P., D.C.L., F.R.S. Charles Darwin, Esq., M.A., F.R.S., Sec. G.S. Professor Faraday, D.C.L., F.R.S. Sir David Brewster, K.H., LL.D., F.R.S. Rev. Prof. Willis, M.A., F.R.S.	Captain Tindal, R.N. William Wills, Esq. Bell Fletcher, Esq., M.D. James Chance, Esq.
SIR DAVID BREWSTER, K.H., LL.D., F.R.S. L. & E., Principal of the United College of St. Salvator and St. Leonard, St. Andrews EDINBURGH, July 21, 1850.	The Right Hon. the Lord Provost of Edinburgh The Earl of Cathcart, K.C.B., F.R.S.E. The Earl of Rosebery, K.T., D.C.L., F.R.S. The Right Hon. David Boyle (Lord Justice-General), F.R.S.E. General Sir Thomas M. Brisbane, Bart., D.C.L., F.R.S., Pres. R.S.E. The Very Rev. John Lee, D.D., V.P.R.S.E., Principal of the University of Edinburgh. Professor W. P. Alison, M.D., V.P.R.S.E. Professor J. D. Forbes, F.R.S., Sec. R.S.E.	Rev. Professor Kelland, M.A., F.R.S. L. & E. Professor Balfour, M.D., F.R.S.E., F.L.S. James Tod, Esq., F.R.S.E.
GEORGE BIDDELL AIRY, Esq., D.C.L., F.R.S., Astronomer Royal IPSWICH, July 2, 1851.	The Lord Rendlesham, M.P. The Lord Bishop of Norwich Rev. Professor Sedgwick, M.A., F.R.S. Rev. Professor Henslow, M.A., F.L.S. Sir John P. Boileau, Bart., F.R.S. Sir William F. F. Middleton, Bart. J. C. Cobbold, Esq., M.P. T. B. Western, Esq.	Charles May, Esq., F.R.A.S. Dillwyn Sims, Esq. George Arthur Biddell, Esq. George Ransome, Esq., F.L.S.
COLONEL EDWARD SABINE, Royal Artillery, Treas. & V.P. of the Royal Society BELFAST, September 1, 1852.	The Earl of Enniskillen, D.C.L., F.R.S. The Earl of Rosse, Pres. R.S., M.R.I.A. Sir Henry T. De la Beche, F.R.S. Rev. Edward Hincks, D.D., M.R.I.A. Rev. P. S. Henry, D.D., Pres. Queen's College, Belfast Rev. T. R. Robinson, D.D., Pres. R.I.A., F.R.A.S. Professor G. G. Stokes, F.R.S. Professor Stevelly, LL.D.	W. J. C. Allen, Esq. William M'Gee, Esq., M.D. Professor W. P. Wilson.
WILLIAM HOPKINS, Esq., M.A., V.P.R.S., F.G.S., Pres. Camb. Phil. Society HULL, September 7, 1853.	The Earl of Carlisle, F.R.S. Lord Londesborough, F.R.S. Professor Faraday, D.C.L., F.R.S. Rev. Prof. Sedgwick, M.A., F.R.S. Charles Frost, Esq., F.S.A., Pres. of the Hull Lit. and Phil. Society William Spence, Esq., F.R.S. Lieut.-Col. Sykes, F.R.S. Professor Wheatstone, F.R.S.	Henry Cooper, Esq., M.D., V.P. Hull Lit. & Phil. Society. Bethel Jacobs, Esq., Pres. Hull Mechanics' Inst.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The EARL OF HARROWBY, F.R.S. LIVERPOOL, September 20, 1854.	The Lord Wrottesley, M.A., F.R.S., F.R.A.S. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. Professor Owen, M.D., LL.D., F.R.S., F.L.S., F.G.S. Rev. Professor Whewell, D.D., F.R.S., Hon. M.R.I.A., F.G.S., Master of Trinity College, Cambridge William Lassell, Esq., F.R.S. L. & E., F.R.A.S. Joseph Brooks Yates, Esq., F.S.A., F.R.G.S.	Joseph Dickinson, Esq., M.D., F.R.S. Thomas Inman, Esq., M.D.
The DUKE OF ARGYLL, F.R.S., F.G.S. GLASGOW, September 12, 1855.	The Very Rev. Principal Macfarlane, D.D. Sir William Jardine, Bart., F.R.S.E. Sir Charles Lyell, M.A., LL.D., F.R.S. James Smith, Esq., F.R.S. L. & E. Walter Crum, Esq., F.R.S. Thomas Graham, Esq., M.A., F.R.S., Master of the Royal Mint Professor William Thomson, M.A., F.R.S.	John Strang, Esq., LL.D. Professor Thomas Anderson, M.D. William Gourlie, Esq.
CHARLES G. B. DAUBENY, Esq., M.D., LL.D., F.R.S., Professor of Botany in the University of Oxford. CHELTENHAM, August 6, 1856.	The Earl of Ducie, F.R.S., F.G.S. The Lord Bishop of Gloucester and Bristol Sir Roderick I. Murchison, G.C.St.S., D.C.L., F.R.S. Thomas Barwick Lloyd Baker, Esq. The Rev. Francis Close, M.A.	Capt. Robinson, R.A. Richard Beamish, Esq., F.R.S. John West Hugell, Esq.
The REV. HUMPHREY LLOYD, D.D., D.C.L., F.R.S. L. & E., V.P.R.I.A. DUBLIN, August 26, 1857.	The Right Hon. the Lord Mayor of Dublin The Provost of Trinity College, Dublin The Marquis of Kildare. Lord Talbot de Malahide The Lord Chancellor of Ireland The Lord Chief Baron, Dublin Sir William R. Hamilton, LL.D., F.R.A.S., Astronomer Royal of Ireland Lieut.-Colonel Larcom, R.E., LL.D., F.R.S. Richard Griffith, Esq., LL.D., M.R.I.A., F.R.S.E., F.G.S.	Lundy E. Foote, Esq. Rev. Professor Jellett, F.T.C.D. W. Neilson Hancock, Esq., LL.D.
RICHARD OWEN, Esq., M.D., D.C.L., V.P.R.S., F.L.S., F.G.S., Superintendent of the Natural History Departments of the British Museum. LEEDS, September 22, 1858.	The Lord Monteagle, F.R.S. The Lord Viscount Goderich, M.P., F.R.G.S. The Right Hon. M. T. Baines, M.A., M.P. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. The Rev. W. Whewell, D.D., F.R.S., Hon. M.R.I.A., F.G.S., F.R.A.S., Master of Trinity College, Cambridge James Garth Marshall, Esq., M.A., F.G.S. R. Monckton Milnes, Esq., D.C.L., M.P., F.R.G.S.	Rev. Thomas Hincks, B.A. W. Sykes Ward, Esq., F.C.S. Thomas Wilson, Esq., M.A.
HIS ROYAL HIGHNESS THE PRINCE CONSORT. ABERDEEN, September 14, 1859.	The Duke of Richmond, K.G., F.R.S. The Earl of Aberdeen, LL.D., K.G., K.T., F.R.S. The Lord Provost of the City of Aberdeen Sir John F. W. Herschel, Bart., M.A., D.C.L., F.R.S. Sir David Brewster, K.H., D.C.L., F.R.S. Sir Roderick I. Murchison, G.C.St.S., D.C.L., F.R.S. The Rev. W. V. Harcourt, M.A., F.R.S. The Rev. T. R. Robinson, D.D., F.R.S. A. Thomson, Esq., LL.D., F.R.S., Convener of the County of Aberdeen	Professor J. Nicol, F.R.S.E., F.G.S. Professor Fuller, M.A. John F. White, Esq.
The LORD WROTTESLEY, M.A., V.P.R.S., F.R.A.S. OXFORD, June 27, 1860.	The Earl of Derby, K.G., P.C., D.C.L., Chancellor of the Univ. of Oxford The Rev. F. Jeune, D.C.L., Vice-Chancellor of the University of Oxford The Duke of Marlborough, D.C.L., F.G.S., Lord Lieutenant of Oxfordshire The Earl of Rosse, K.P., M.A., F.R.S., F.R.A.S. The Lord Bishop of Oxford, D.D., F.R.S. The Very Rev. H. G. Liddell, D.D., Dean of Christ Church, Oxford Professor Daubeny, M.D., LL.D., F.R.S., F.L.S., F.G.S. Professor Acland, M.D., F.R.S. Professor Donkin, M.A., F.R.S., F.R.A.S.	George Rolleston, Esq., M.D., F.L.S. H. J. S. Smith, Esq., M.A., F.C.S. George Griffith, Esq., M.A., F.C.S.

WILLIAM FAIRBAIRN, Esq., LL.D., C.E., F.R.S. MANCHESTER, September 4, 1861.	The Earl of Ellesmere, F.R.G.S. The Lord Stanley, M.P., D.C.L., F.R.G.S. The Lord Bishop of Manchester, D.D., F.R.S., F.G.S. Sir Philip de Malpas Grey Egerton, Bart., M.P., F.R.S., F.G.S. Sir Benjamin Heywood, Bart., F.R.S. Thomas Bazley, Esq., M.P. James Aspinall Turner, Esq., M.P. James Prescott Joule, Esq., LL.D., F.R.S., Pres. Lit. & Phil. Soc. Manchester Professor E. Hodgkinson, F.R.S., M.R.I.A., M.I.C.E. Joseph Whitworth, Esq., F.R.S., M.Inst.C E.	R. D. Darbishire, Esq., B.A., F.G S. Alfred Neild, Esq. Arthur Ransome, Esq., M.A. Professor H. E. Roscoe, B.A.
The REV. R. WILLIS, M.A., F.R.S., Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge CAMBRIDGE, October 1, 1862.	The Rev. the Vice-Chancellor of the University of Cambridge The Very Rev. Harvey Goodwin, D.D., Dean of Ely The Rev. W. Whewell, D.D., F.R.S., Master of Trinity College, Cambridge The Rev. Professor Sedgwick, M.A., D.C.L., F.R.S. The Rev. J. Challis, M.A., F.R.S. G. B. Airy, Esq., M.A., D.C.L., F.R.S., Astronomer Royal Professor G. G. Stokes, M.A., D.C.L., Sec. R.S. Professor J. C. Adams, M.A., D.C.L., F.R.S., Pres. C.P.S.	Professor C. C. Babington, M.A., F.R.S., F.L.S. Professor G. D. Liveing, M.A. The Rev. N. M. Ferrers, M.A.
SIR W. ARMSTRONG, C.B., LL.D., F.R.S. NEWCASTLE-ON-TYNE, August 26, 1863.	Sir Walter C. Trevelyan, Bart., M.A. Sir Charles Lyell, LL.D., D.C.L., F.R.S., F.G.S. Hugh Taylor, Esq., Chairman of the Coal Trade Isaac Lowthian Bell, Esq., Mayor of Newcastle Nicholas Wood, Esq., President of the Northern Institute of Mining Engineers Rev. Temple Chevallier, B.D., F.R.A.S. William Fairbairn, Esq., LL.D., F.R.S.	A. Noble, Esq. Augustus H. Hunt, Esq. R. C. Clapham, Esq.
SIR CHARLES LYELL, Bart., M.A., D.C.L., F.R.S. BATH, September 14, 1864.	The Right Hon. the Earl of Cork and Orrery, Lord-Lieutenant of Somersetshire The Most Noble the Marquis of Bath The Right Hon. Earl Nelson The Right Hon. Lord Portman The Very Rev. the Dean of Hereford The Venerable the Archdeacon of Bath W. Tite, Esq., M.P., F.R.S., F.G.S., F.S.A. A. E. Way, Esq., M.P. Francis H. Dickinson, Esq. W. Sanders, Esq., F.R.S., F.G.S.	C. Moore, Esq., F.G.S. C. E. Davis, Esq. The Rev. H. H. Winwood, M.A.
JOHN PHILLIPS, Esq., M.A., LL.D., F.R.S., F.G.S., Professor of Geology in the University of Oxford BIRMINGHAM, September 6, 1865.	The Right Hon. the Earl of Lichfield, Lord-Lieutenant of Staffordshire The Right Hon. the Earl of Dudley The Right Hon. Lord Leigh, Lord-Lieutenant of Warwickshire The Right Hon. Lord Lyttelton, Lord-Lieutenant of Worcestershire The Right Hon. Lord Wrottesley, M.A., D.C.L., F.R.S., F.R.A.S. The Right Rev. the Lord Bishop of Worcester The Right Hon. C. B. Adderley, M.P. William Scholefield, Esq., M.P. F. Osler, Esq., F.R.S. J. T. Chance, Esq. The Rev. Charles Evans, M.A.	William Mathews, jun., Esq. M.A., F.G.S. John Henry Chamberlain, Esq. The Rev. G. D. Boyle, M.A.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
WILLIAM R. GROVE, Esq., Q.C., M.A., F.R.S. NOTTINGHAM, August 22, 1866.	His Grace the Duke of Devonshire, Lord-Lieutenant of Derbyshire His Grace the Duke of Rutland, Lord-Lieutenant of Leicestershire The Right Hon. Lord Belper, Lord-Lieutenant of Nottinghamshire The Right Hon. J. E. Denison, M.P. J. C. Webb, Esq., High-Sheriff of Nottinghamshire Thomas Graham, Esq., F.R.S., Master of the Mint Joseph Hooker, Esq., M.D., F.R.S., F.L.S. John Russell Hinds, Esq., F.R.S., F.R.A.S. T. Close, Esq.	Dr. Robertson. Edward J. Lowe, Esq., F.R.A.S., F.L.S. The Rev. J. F. M'Callan, M.A.
HIS GRACE THE DUKE OF BUCCLEUCH, K.G., D.C.L., F.R.S. DUNDEE, September 4, 1867.	The Right Hon. the Earl of Airlie, K.T. The Right Hon. the Lord Kinnaird, K.T. Sir John Ogilvy, Bart., M.P. Sir Roderick I. Murchison, Bart., K.C.B., LL.D., F.R.S., F.G.S., &c. Sir David Baxter, Bart. Sir David Brewster, D.C.L., F.R.S., Principal of the University of Edinburgh James D. Forbes, Esq., LL.D., F.R.S., Principal of the United College of St. Salvator and St. Leonard, University of St. Andrews	J. Henderson, jun., Esq. John Austin Lake Gloag, Esq. Patrick Anderson, Esq.
JOSEPH DALTON HOOKER, Esq., M.D., D.C.L., F.R.S., F.L.S. NORWICH, August 19, 1868.	The Right Hon. the Earl of Leicester, Lord-Lieutenant of Norfolk Sir John Peter Boileau, Bart., F.R.S. The Rev. Adam Sedgwick, M.A., LL.D., F.R.S., F.G.S., &c., Woodwardian Professor of Geology in the University of Cambridge Sir John Lubbock, Bart., F.R.S., F.L.S., F.G.S. John Couch Adams, Esq., M.A., D.C.L., F.R.S., F.R.A.S., Lowndean Professor of Astronomy and Geometry in the University of Cambridge Thomas Brightwell, Esq.	Dr. Donald Dalrymple. Rev. Joseph Crompton, M.A. Rev. Canon Hinds Howell.
PROFESSOR GEORGE G. STOKES, D.C.L., F.R.S. EXETER, August 18, 1869.	The Right Hon. the Earl of Devon The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., &c. Sir John Bowring, LL.D., F.R.S. William B. Carpenter, Esq., M.D., F.R.S., F.L.S. Robert Were Fox, Esq., F.R.S. W. H. Fox Talbot, Esq., M.A., LL.D., F.R.S., F.L.S.	Henry S. Ellis, Esq., F.R.A.S. John C. Bowring, Esq. The Rev. R. Kirwan.
PROFESSOR T. H. HUXLEY, LL.D., F.R.S. F.G.S. LIVERPOOL, September 14, 1870.	The Right Hon. the Earl of Derby, LL.D., F.R.S. Sir Philip de Malpas Grey Egerton, Bart., M.P. The Right Hon. W. E. Gladstone, D.C.L., M.P. S. R. Graves, Esq., M.P. Sir Joseph Whitworth, Bart., LL.D., D.C.L., F.R.S. James P. Joule, Esq., LL.D., D.C.L., F.R.S. Joseph Mayer, Esq., F.S.A., F.R.G.S.	Rev. W. Banister. Reginald Harrison, Esq. Rev. Henry H. Higgins, M.A. Rev. Dr. A. Hume, F.S.A.
PROFESSOR SIR WILLIAM THOMSON, M.A., LL.D., F.R.S. L. & E. EDINBURGH, August 2, 1871.	His Grace the Duke of Buccleuch, K.G., D.C.L., F.R.S. The Right Hon. the Lord Provost of Edinburgh The Right Hon. John Inglis, LL.D., Lord Justice-General of Scotland Sir Alexander Grant, Bart., M.A., Principal of the University of Edinburgh Sir Roderick I. Murchison, Bart., K.C.B., G.C.St.S., D.C.L., F.R.S. Sir Charles Lyell, Bart., D.C.L., F.R.S., F.G.S. Dr. Lyon Playfair, C.B., M.P., F.R.S. Professor Christison, M.D., D.C.L., Pres. R.S.E. Professor Balfour, F.R.S. L. & E.	Professor A. Crum Brown, M.D., F.R.S.E. J. D. Marwick, Esq., F.R.S.E.

W. B. CARPENTER, Esq., M.D., LL.D., F.R.S., F.L.S. BRIGHTON, August 14, 1872.	The Right Hon. the Earl of Chichester, Lord-Lieutenant of the County of Sussex. His Grace the Duke of Norfolk His Grace the Duke of Richmond, K.G., P.C., D.C.L. His Grace the Duke of Devonshire, K.G., D.C.L., F.G.S. Sir John Lubbock, Bart., M.P., F.R.S., F.L.S., F.G.S. Dr. Sharpey, LL.D., Sec. R.S., F.L.S. Joseph Prestwich, Esq., F.R.S., Pres. G.S.	Charles Carpenter, Esq The Rev. Dr. Griffith. Henry Willett, Esq.
PROFESSOR ALEXANDER W. WILLIAMSON, Ph.D., F.R.S., F.C.S. BRADFORD, September 17, 1873.	The Right Hon. the Earl of Rosse, F.R.S., F.R.A.S. The Right Hon. Lord Houghton, D.C.L., F.R.S. The Right Hon. W. E. Forster, M.P. The Mayor of Bradford. Sir John Hawkshaw, F.R.S., F.G.S. J. P. Gassiot, Esq., D.C.L., F.R.S. Professor Phillips, D.C.L., F.R.S.	The Rev. J. R. Campbell, D.D. Richard Goddard, Esq. Peile Thompson, Esq.
PROFESSOR J. TYNDALL, D.C.L., LL.D., F.R.S. BELFAST, August 19, 1874.	The Right Hon. the Earl of Enniskillen, D.C.L., F.R.S. The Right Hon. the Earl of Rosse, F.R.S. Sir Richard Wallace, Bart., M.P. The Rev. Dr. Henry. Dr. Andrews, F.R.S. The Rev. Dr. Robinson, F.R.S. Professor Stokes, D.C.L., F.R.S.	W. Quartus Ewart, Esq. Professor G. Fuller, C.E. T. Sinclair, Esq.
SIR JOHN HAWKSHAW, C.E., F.R.S., F.G.S. BRISTOL, August 25, 1875.	The Right Hon. the Earl of Ducie, F.R.S., F.G.S. The Right Hon. Sir Stafford H. Northcote, Bart., C.B., M.P., F.R.S. The Mayor of Bristol Major-General Sir Henry C. Rawlinson, K.C.B., LL.D., F.R.S., F.R.G.S. Dr. W. B. Carpenter, LL.D., F.R.S., F.L.S., F.G.S. W. Sanders, Esq., F.R.S., F.G.S.	W. Lant Carpenter, Esq., B.A., B.Sc., F.C.S. John H. Clarke, Esq.
PROFESSOR THOMAS ANDREWS, M.D., LL.D., F.R.S., Hon. F.R.S.E. GLASGOW, September 6, 1876.	His Grace the Duke of Argyll, K.T., LL.D., F.R.S. L. & E., F.G.S. The Hon. the Lord Provost of Glasgow Sir William Stirling Maxwell, Bart., M.A., M.P. Professor Sir William Thomson, M.A., LL.D., D.C.L., F.R.S. L. & E. Professor Allen Thomson, M.D., LL.D., F.R.S. L. & E. Professor A. C. Ramsay, LL.D., F.R.S., F.G.S. James Young, Esq., F.R.S., F.C.S.	Dr. W. G. Blackie, F.R.G.S. James Grahame, Esq. J. D. Marwick, Esq.
PROFESSOR ALLEN THOMSON, M.D., LL.D., F.R.S. L. & E. PLYMOUTH, August 15, 1877.	The Right Hon. the Earl of Mount-Edgcumbe The Right Hon. Lord Blachford, K.C.M.G. William Spottiswoode, Esq., M.A., LL.D., F.R.S., F.R.A.S., F.R.G.S. William Froude, Esq., M.A., C.E., F.R.S. Charles Spence Bate, Esq., F.R.S., F.L.S.	William Adams, Esq. William Square, Esq. Hamilton Whiteford, Esq.
WILLIAM SPOTTISWOODE, Esq., M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S. DUBLIN, August 14, 1878.	The Right Hon. the Lord Mayor of Dublin The Provost of Trinity College, Dublin His Grace the Duke of Abercorn, K.G. The Right Hon. the Earl of Enniskillen, D.C.L., F.R.S., F.G.S. The Right Hon. the Earl of Rosse, B.A., D.C.L., F.R.S., F.R.A.S., M.R.I.A. The Right Hon. Lord O'Hagan, M.R.I.A. Professor G. G. Stokes, M.A., D.C.L., LL.D., Sec. R.S.	Professor R. S. Ball, M.A., F.R.S. James Goff, Esq. John Norwood, Esq., LL.D. Professor G. Sigerson, M.D.
PROFESSOR G. J. ALLMAN, M.D., LL.D., F.R.S. L. & E., M.R.I.A., Pres. L.S. SHEFFIELD, August 20, 1879.	His Grace the Duke of Devonshire, K.G., M.A., LL.D., F.R.S., F.R.G.S. The Right Hon. the Earl Fitzwilliam, K.G., F.R.G.S. The Right Hon. the Earl of Wharncliffe, F.R.G.S. W. H. Brittain, Esq. (Master Cutler) Professor T. H. Huxley, Ph.D., LL.D., Sec. R.S., F.L.S., F.G.S. Professor W. Odling, M.B., F.R.S., F.C.S.	H. Clifton Sorby, Esq., LL.D., F.R.S., F.G.S. J. F. Moss, Esq.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
ANDREW CROMBIE RAMSAY, Esq., LL.D., F.R.S., V.P.G.S., Director-General of the Geological Survey of the United Kingdom, and of the Museum of Practical Geology. SWANSEA, August 25, 1880.	The Right Hon. the Earl of Jersey The Mayor of Swansea The Hon. Sir W. R. Grove, M.A., D.C.L., F.R.S. H. Hussey Vivian, Esq., M.P., F.G.S. L. Ll. Dillwyn, Esq., M.P., F.L.S., F.G.S. J. Gwyn Jeffreys, Esq., LL.D., F.R.S., F.L.S., Treas. G.S., F.R.G.S.	W. Morgan Esq., Ph.D., F.C.S. James Strick, Esq.
SIR JOHN LUBBOCK, Bart., M.P., D.C.L., LL.D., F.R.S., Pres. L.S., F.G.S. YORK, August 31, 1881.	His Grace the Archbishop of York, D.D., F.R.S. The Right Hon. the Lord Mayor of York The Right Hon. Lord Houghton, D.C.L., F.R.S., F.R.G.S. The Venerable Archdeacon Creyke, M.A. The Hon. Sir W. R. Grove, M.A., D.C.L., F.R.S. Professor G. G. Stokes, M.A., D.C.L., LL.D., Sec. R.S. Sir John Hawkshaw, C.E., F.R.S., F.G.S., F.R.G.S. Allen Thomson, Esq., M.D., LL.D., F.R.S. L. & E. Professor Allman, M.D., LL.D., F.R.S. L. & E., F.L.S.	Rev. Thomas Adams, M.A. Tempest Anderson, Esq., M.D., B.Sc.
C. W. SIEMENS, Esq., D.C.L., LL.D., F.R.S., F.C.S., M.Inst.C.E. SOUTHAMPTON, August 23, 1882.	The Right Hon. the Lord Mount-Temple Captain Sir F. J. Evans, K.C.B., F.R.S., F.R.A.S., F.R.G.S., Hydrographer to the Admiralty F. A. Abel, Esq., C.B., F.R.S., V.P.C.S., Director of the Chemical Establishment of the War Department Professor De Chaumont, M.D., F.R.S. Major-General A. C. Cooke, R.E., C.B., F.R.G.S., Director-General of the Ordnance Survey. Wyndham S. Portal, Esq. Professor Prestwich, M.A., F.R.S., F.G.S., F.C.S. Philip Lutley Sclater, Esq., M.A., Ph.D., F.R.S., F.L.S., F.G.S.	C. W. A. Jellicoe, Esq. John E. Le Feuvre, Esq. Morris Miles, Esq.
ARTHUR CAYLEY, Esq., M.A., D.C.L., LL.D., F.R.S., V.P.R.A.S., Sadlerian Professor of Pure Mathematics in the University of Cambridge. SOUTHPORT, September 19, 1883.	The Right Hon. the Earl of Derby, M.A., LL.D., F.R.S., F.R.G.S. The Right Hon. the Earl of Crawford and Balcarres, LL.D., F.R.S., F.R.A.S. The Right Hon. the Earl of Lathom Principal J. W. Dawson, C.M.G., M.A., LL.D., F.R.S., F.G.S. J. G. Greenwood, Esq., LLD., Vice-Chancellor of the Victoria University Professor H. E. Roscoe, Ph.D., LL.D., F.R.S., F.C.S.	J. H. Ellis, Esq. Dr. Vernon. T. W. Willis, Esq.
The RIGHT HON. LORD RAYLEIGH, M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S., Professor of Experimental Physics in the University of Cambridge. MONTREAL, August 27, 1884.	His Excellency the Governor-General of Canada, G.C.M.G., LL.D. The Right Hon. Sir John Alexander Macdonald, K.C.B., D.C.L., LL.D. The Right Hon. Sir Lyon Playfair, K.C.B., M.P., Ph.D., LL.D., F.R.S.L. & E., F.C.S. The Hon. Sir Alexander Tilloch Galt, G.C.M.G. The Hon. Sir Charles Tupper, K.C.M.G. Chief Justice Sir A. A. Dorion, C.M.G. Principal Sir William Dawson, C.M.G., M.A., LL.D., F.R.S., F.G.S. The Hon. Dr. Chauveau. Professor Edward Frankland, M.D., D.C.L., Ph.D., LL.D., F.R.S., F.C.S. W. H. Hingston, Esq., M.D., D.C.L., L.R.C.S.E. Thomas Sterry Hunt, Esq., M.A., D.Sc., LL.D., F.R.S.	S. E. Dawson, Esq. R. A. Ramsay, Esq. S. Rivard, Esq. S. C. Stevenson, Esq. Thos. White, Esq., M.P.
The RIGHT HON. SIR LYON PLAYFAIR, K.C.B., M.P., Ph.D., LL.D., F.R.S. L. & E., F.C.S. ABERDEEN, September 9, 1885.	His Grace the Duke of Richmond and Gordon, K.G., D.C.L., Chancellor of the University of Aberdeen The Right Hon. the Earl of Aberdeen, LL.D., Lord-Lieutenant of Aberdeenshire The Right Hon. the Earl of Crawford and Balcarres, M.A., LL.D., F.R.S., F.R.A.S. James Matthews, Esq., Lord Provost of the City of Aberdeen Professor Sir William Thomson, M.A., LL.D., F.R.S. L. & E., F.R.A.S. Alexander Bain, Esq., M.A., LL.D., Rector of the University of Aberdeen The Very Rev. Principal Pirie, D.D., Vice-Chancellor of the University of Aberdeen Professor W. H. Flower, LL.D., F.R.S., F.L.S., Pres. Z.S., F.G.S.,	J. W. Crombie, Esq., M.A. Angus Fraser, Esq., M.A., M.D., F.C.S. Professor G. Pirie, M.A.

Presidents and Secretaries of the Sections of the Association.

Date and Place	Presidents	Secretaries

MATHEMATICAL AND PHYSICAL SCIENCES.

COMMITTEE OF SCIENCES, I.—MATHEMATICS AND GENERAL PHYSICS.

1832. Oxford......	Davies Gilbert, D.C.L., F.R.S.	Rev. H. Coddington.
1833. Cambridge	Sir D. Brewster, F.R.S.	Prof. Forbes.
1834. Edinburgh	Rev. W. Whewell, F.R.S.	Prof. Forbes, Prof. Lloyd.

SECTION A.—MATHEMATICS AND PHYSICS.

1835. Dublin......	Rev. Dr. Robinson	Prof. Sir W. R. Hamilton, Prof. Wheatstone.
1836. Bristol......	Rev. William Whewell, F.R.S.	Prof. Forbes, W. S. Harris, F. W. Jerrard.
1837. Liverpool...	Sir D. Brewster, F.R.S.	W. S. Harris, Rev. Prof. Powell, Prof. Stevelly.
1838. Newcastle	Sir J. F. W. Herschel, Bart., F.R.S.	Rev. Prof. Chevallier, Major Sabine, Prof. Stevelly.
1839. Birmingham	Rev. Prof. Whewell, F.R.S....	J. D. Chance, W. Snow Harris, Prof. Stevelly.
1840. Glasgow ...	Prof. Forbes, F.R.S............	Rev. Dr. Forbes, Prof. Stevelly, Arch. Smith.
1841. Plymouth	Rev. Prof. Lloyd, F.R.S.	Prof. Stevelly.
1842. Manchester	Very Rev. G. Peacock, D.D., F.R.S.	Prof. M'Culloch, Prof. Stevelly, Rev. W. Scoresby.
1843. Cork.........	Prof. M'Culloch, M.R.I.A. ...	J. Nott, Prof. Stevelly.
1844. York.........	The Earl of Rosse, F.R.S. ...	Rev. Wm. Hey, Prof. Stevelly.
1845. Cambridge	The Very Rev. the Dean of Ely.	Rev. H. Goodwin, Prof. Stevelly, G. G. Stokes.
1846. Southampton.	Sir John F. W. Herschel, Bart., F.R.S.	John Drew, Dr. Stevelly, G. G. Stokes.
1847. Oxford......	Rev. Prof. Powell, M.A., F.R.S.	Rev. H. Price, Prof. Stevelly, G. G. Stokes.
1848. Swansea ...	Lord Wrottesley, F.R.S.	Dr. Stevelly, G. G. Stokes.
1849. Birmingham	William Hopkins, F.R.S.......	Prof. Stevelly, G. G. Stokes, W. Ridout Wills.
1850. Edinburgh	Prof. J. D. Forbes, F.R.S., Sec. R.S.E.	W. J. Macquorn Rankine, Prof. Smyth, Prof. Stevelly, Prof. G. G. Stokes.
1851. Ipswich ...	Rev. W. Whewell, D.D., F.R.S.	S. Jackson, W. J. Macquorn Rankine, Prof. Stevelly, Prof. G. G. Stokes.
1852. Belfast......	Prof. W. Thomson, M.A., F.R.S. L. & E.	Prof. Dixon, W. J. Macquorn Rankine, Prof. Stevelly, J. Tyndall.
1853. Hull.........	The Very Rev. the Dean of Ely, F.R.S.	B. Blaydes Haworth, J. D. Sollitt, Prof. Stevelly, J. Welsh.
1854. Liverpool...	Prof. G. G. Stokes, M.A., Sec. R.S.	J. Hartnup, H. G. Puckle, Prof. Stevelly, J. Tyndall, J. Welsh.
1855. Glasgow ...	Rev. Prof. Kelland, M.A., F.R.S. L. & E.	Rev. Dr. Forbes, Prof. D. Gray, Prof. Tyndall.
1856. Cheltenham	Rev. R. Walker, M.A., F.R.S.	C. Brooke, Rev. T. A. Southwood, Prof. Stevelly, Rev. J. C. Turnbull.
1857. Dublin......	Rev. T. R. Robinson, D.D., F.R.S., M.R.I.A.	Prof. Curtis, Prof. Hennessy, P. A. Ninnis, W. J. Macquorn Rankine, Prof. Stevelly.
1858. Leeds	Rev. W. Whewell, D.D., V.P.R.S.	Rev. S. Earnshaw, J. P. Hennessy, Prof. Stevelly, H. J. S. Smith, Prof. Tyndall.

Date and Place	Presidents	Secretaries
1859. Aberdeen...	The Earl of Rosse, M.A., K.P., F.R.S.	J. P. Hennessy, Prof. Maxwell, H. J. S. Smith, Prof. Stevelly.
1860. Oxford......	Rev. B. Price, M.A., F.R.S....	Rev. G. C. Bell, Rev. T. Rennison, Prof. Stevelly.
1861. Manchester	G. B. Airy, M.A., D.C.L., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1862. Cambridge	Prof. G. G. Stokes, M.A., F.R.S.	Prof. R. B. Clifton, Prof. H. J. S. Smith, Prof. Stevelly.
1863. Newcastle	Prof. W. J. Macquorn Rankine, C.E., F.R.S.	Rev. N. Ferrers, Prof. Fuller, F. Jenkin, Prof. Stevelly, Rev. C. T. Whitley.
1864. Bath.........	Prof. Cayley, M.A., F.R.S., F.R.A.S.	Prof. Fuller, F. Jenkin, Rev. G. Buckle, Prof. Stevelly.
1865. Birmingham	W. Spottiswoode, M.A., F.R.S., F.R.A.S.	Rev. T. N. Hutchinson, F. Jenkin, G. S. Mathews, Prof. H. J. S. Smith, J. M. Wilson.
1866. Nottingham	Prof. Wheatstone, D.C.L., F.R.S.	Fleeming Jenkin, Prof. H. J. S. Smith, Rev. S. N. Swann.
1867. Dundee ...	Prof. Sir W. Thomson, D.C.L., F.R.S.	Rev. G. Buckle, Prof. G. C. Foster, Prof. Fuller, Prof. Swan.
1868. Norwich ...	Prof. J. Tyndall, LL.D., F.R.S.	Prof. G. C. Foster, Rev. R. Harley, R. B. Hayward.
1869. Exeter......	Prof. J. J. Sylvester, LL.D., F.R.S.	Prof. G. C. Foster, R. B. Hayward, W. K. Clifford.
1870. Liverpool...	J. Clerk Maxwell, M.A., LL.D., F.R.S.	Prof. W. G. Adams, W. K. Clifford, Prof. G. C. Foster, Rev. W. Allen Whitworth.
1871. Edinburgh	Prof. P. G. Tait, F.R.S.E. ...	Prof. W. G. Adams, J. T. Bottomley, Prof. W. K. Clifford, Prof. J. D. Everett, Rev. R. Harley.
1872. Brighton...	W. De La Rue, D.C.L., F.R.S.	Prof. W. K. Clifford, J. W. L. Glaisher, Prof. A. S. Herschel, G. F. Rodwell.
1873. Bradford...	Prof. H. J. S. Smith, F.R.S.	Prof. W. K. Clifford, Prof. Forbes, J. W. L. Glaisher, Prof. A. S. Herschel.
1874. Belfast......	Rev. Prof. J. H. Jellett, M.A., M.R.I.A.	J. W. L. Glaisher, Prof. Herschel, Randal Nixon, J. Perry, G. F. Rodwell.
1875. Bristol......	Prof. Balfour Stewart, M.A., LL.D., F.R.S.	Prof. W. F. Barrett, J. W. L. Glaisher, C. T. Hudson, G. F. Rodwell.
1876. Glasgow ...	Prof. Sir W. Thomson, M.A., D.C.L., F.R.S.	Prof. W. F. Barrett, J. T. Bottomley, Prof. G. Forbes, J. W. L. Glaisher, T. Muir.
1877. Plymouth...	Prof. G. C. Foster, B.A., F.R.S., Pres. Physical Soc.	Prof. W. F. Barrett, J. T. Bottomley, J. W. L. Glaisher, F. G. Landon.
1878. Dublin......	Rev. Prof. Salmon, D.D., D.C.L., F.R.S.	Prof. J. Casey, G. F. Fitzgerald, J. W. L. Glaisher, Dr. O. J. Lodge.
1879. Sheffield ...	George Johnstone Stoney, M.A., F.R.S.	A. H. Allen, J. W. L. Glaisher, Dr. O. J. Lodge, D. MacAlister.
1880. Swansea ...	Prof. W. Grylls Adams, M.A., F.R.S.	W. E. Ayrton, J. W. L. Glaisher, Dr. O. J. Lodge, D. MacAlister.
1881. York.........	Prof. Sir W. Thomson, M.A., LL.D., D.C.L., F.R.S.	Prof. W. E. Ayrton, Prof. O. J. Lodge, D. MacAlister, Rev. W. Routh.
1882. Southampton.	Rt. Hon. Prof. Lord Rayleigh, M.A., F.R.S.	W. M. Hicks, Prof. O. J. Lodge, D. MacAlister, Rev. G. Richardson.
1883. Southport	Prof. O. Henrici, Ph.D., F.R.S.,	W. M. Hicks, Prof. O. J. Lodge, D. MacAlister, Prof. R. C. Rowe.
1884. Montreal ...	Prof. Sir W. Thomson, M.A., LL.D., D.C.L., F.R.S	C. Carpmael, W. M. Hicks, Prof. A. Johnson, Prof. O. J. Lodge, Dr. D. MacAlister.
1885. Aberdeen...	Prof. G. Chrystal, M.A., F.R.S.E.	R. E. Baynes, R. T. Glazebrook, Prof. W. M. Hicks, Prof. W. Ingram.

CHEMICAL SCIENCE.

COMMITTEE OF SCIENCES, II.—CHEMISTRY, MINERALOGY.

Date and Place	Presidents	Secretaries
1832. Oxford......	John Dalton, D.C.L., F.R.S.	James F. W. Johnston.
1833. Cambridge	John Dalton, D.C.L., F.R.S.	Prof. Miller.
1834. Edinburgh	Dr. Hope.........................	Mr. Johnston, Dr Christison.

SECTION B.—CHEMISTRY AND MINERALOGY.

1835. Dublin......	Dr. T. Thomson, F.R.S.	Dr. Apjohn, Prof. Johnston.
1836. Bristol......	Rev. Prof. Cumming	Dr. Apjohn, Dr. C. Henry, W. Herapath.
1837. Liverpool...	Michael Faraday, F.R.S.......	Prof. Johnston, Prof. Miller, Dr. Reynolds.
1838. Newcastle	Rev. William Whewell, F.R.S.	Prof. Miller, H. L. Pattinson, Thomas Richardson.
1839. Birmingham	Prof. T. Graham, F.R.S.	Dr. Golding Bird, Dr. J. B. Melson.
1840. Glasgow ...	Dr. Thomas Thomson, F.R.S.	Dr. R. D. Thomson, Dr. T. Clark, Dr. L. Playfair.
1841. Plymouth...	Dr. Daubeny, F.R.S.	J. Prideaux, Robert Hunt, W. M. Tweedy.
1842. Manchester	John Dalton, D.C.L., F.R.S.	Dr. L. Playfair, R. Hunt, J. Graham.
1843. Cork.........	Prof. Apjohn, M.R.I.A.........	R. Hunt, Dr. Sweeny.
1844. York.........	Prof. T. Graham, F.R.S.	Dr. L. Playfair, E. Solly, T. H. Barker.
1845. Cambridge	Rev. Prof. Cumming	R. Hunt, J. P. Joule, Prof. Miller, E. Solly.
1846. Southampton	Michael Faraday, D.C.L., F.R.S.	Dr. Miller, R. Hunt, W. Randall.
1847. Oxford......	Rev. W. V. Harcourt, M.A., F.R.S.	B. C. Brodie, R. Hunt, Prof. Solly.
1848. Swansea ...	Richard Phillips, F.R.S.	T. H. Henry, R. Hunt, T. Williams.
1849. Birmingham	John Percy, M.D., F.R.S.......	R. Hunt, G. Shaw.
1850. Edinburgh	Dr. Christison, V.P.R.S.E.	Dr. Anderson, R. Hunt, Dr. Wilson.
1851. Ipswich ...	Prof. Thomas Graham, F.R.S.	T. J. Pearsall, W. S. Ward.
1852. Belfast......	Thomas Andrews, M.D., F.R.S.	Dr. Gladstone, Prof. Hodges, Prof. Ronalds.
1853. Hull	Prof. J. F. W. Johnston, M.A., F.R.S.	H. S. Blundell, Prof. R. Hunt, T. J. Pearsall.
1854. Liverpool	Prof. W. A. Miller, M.D., F.R.S.	Dr. Edwards, Dr. Gladstone, Dr. Price.
1855. Glasgow ...	Dr. Lyon Playfair, C.B., F.R.S.	Prof. Frankland, Dr. H. E. Roscoe.
1856. Cheltenham	Prof. B. C. Brodie, F.R.S. ...	J. Horsley, P. J. Worsley, Prof. Voelcker.
1857. Dublin......	Prof. Apjohn, M.D., F.R.S., M.R.I.A.	Dr. Davy, Dr. Gladstone, Prof. Sullivan.
1858. Leeds	Sir J. F. W. Herschel, Bart., D.C.L.	Dr. Gladstone, W. Odling, R. Reynolds.
1859. Aberdeen...	Dr. Lyon Playfair, C.B., F.R.S.	J. S. Brazier, Dr. Gladstone, G. D. Liveing, Dr. Odling.
1860. Oxford......	Prof. B. C. Brodie, F.R.S......	A. Vernon Harcourt, G. D. Liveing, A. B. Northcote.
1861. Manchester	Prof. W. A. Miller, M.D., F.R.S.	A. Vernon Harcourt, G. D. Liveing.
1862. Cambridge	Prof. W. A. Miller, M.D., F.R.S.	H. W. Elphinstone, W. Odling, Prof. Roscoe.
1863. Newcastle	Dr. Alex. W. Williamson, F.R.S.	Prof. Liveing, H. L. Pattinson, J. C. Stevenson.
1864. Bath.........	W. Odling, M.B., F.R.S., F.C.S.	A. V. Harcourt, Prof. Liveing, R. Biggs.
1865. Birmingham	Prof. W. A. Miller, M.D., V.P.R.S.	A. V. Harcourt, H. Adkins, Prof. Wanklyn, A. Winkler Wills.

Date and Place	Presidents	Secretaries
1866. Nottingham	H. Bence Jones, M.D., F.R.S.	J. H. Atherton, Prof. Liveing, W. J. Russell, J. White.
1867. Dundee ...	Prof. T. Anderson, M.D., F.R.S.E.	A. Crum Brown, Prof. G. D. Liveing, W. J. Russell.
1868. Norwich ...	Prof. E. Frankland, F.R.S., F.C.S.	Dr. A. Crum Brown, Dr. W. J. Russell, F. Sutton.
1869. Exeter	Dr. H. Debus, F.R.S., F.C.S.	Prof. A. Crum Brown, Dr. W. J. Russell, Dr. Atkinson.
1870. Liverpool...	Prof. H. E. Roscoe, B.A., F.R.S., F.C.S.	Prof. A. Crum Brown, A. E. Fletcher, Dr. W. J. Russell.
1871. Edinburgh	Prof. T. Andrews, M.D., F.R.S.	J. T. Buchanan, W. N. Hartley, T. E. Thorpe.
1872. Brighton ...	Dr. J. H. Gladstone, F.R.S....	Dr. Mills, W. Chandler Roberts, Dr. W. J. Russell, Dr. T. Wood.
1873. Bradford ...	Prof. W. J. Russell, F.R.S....	Dr. Armstrong, Dr. Mills, W. Chandler Roberts, Dr. Thorpe.
1874. Belfast......	Prof. A. Crum Brown, M.D., F.R.S.E., F.C.S.	Dr. T. Cranstoun Charles, W. Chandler Roberts, Prof. Thorpe.
1875. Bristol	A. G. Vernon Harcourt, M.A., F.R.S., F.C.S.	Dr. H. E. Armstrong, W. Chandler Roberts, W. A. Tilden.
1876. Glasgow ...	W. H. Perkin, F.R.S.	W. Dittmar, W. Chandler Roberts, J. M. Thomson, W. A. Tilden.
1877. Plymouth...	F. A. Abel, F.R.S., F.C.S. ...	Dr. Oxland, W. Chandler Roberts, J. M. Thomson.
1878. Dublin	Prof. Maxwell Simpson, M.D., F.R.S., F.C.S.	W. Chandler Roberts, J. M. Thomson, Dr. C. R. Tichborne, T. Wills.
1879. Sheffield ...	Prof. Dewar, M.A., F.R.S.	H. S. Bell, W. Chandler Roberts, J. M. Thomson.
1880. Swansea ...	Joseph Henry Gilbert, Ph.D., F.R.S.	H. B. Dixon, Dr. W. R. Eaton Hodgkinson, P. Phillips Bedson, J. M. Thomson.
1881. York.........	Prof. A. W. Williamson, Ph.D., F.R.S.	P. Phillips Bedson, H. B. Dixon, T. Gough.
1882. Southampton.	Prof. G. D. Liveing, M.A., F.R.S.	P. Phillips Bedson, H. B. Dixon, J. L. Notter.
1883. Southport	Dr. J. H. Gladstone, F.R.S...	Prof. P. Phillips Bedson, H. B. Dixon, H. Forster Morley.
1884. Montreal ...	Prof. Sir H. E. Roscoe, Ph.D., LL.D., F.R.S.	Prof. P. Phillips Bedson, H. B. Dixon, T. McFarlane, Prof. W. H. Pike.
1885. Aberdeen ...	Prof. H. E. Armstrong, Ph.D., F.R.S., Sec. C.S.	Prof. P. Phillips Bedson, H. B. Dixon, H. Forster Morley, Dr. W. J. Simpson.

GEOLOGICAL (AND, UNTIL 1851, GEOGRAPHICAL) SCIENCE.

COMMITTEE OF SCIENCES, III.—GEOLOGY AND GEOGRAPHY.

1832. Oxford	R. I. Murchison, F.R.S.	John Taylor.
1833. Cambridge.	G. B. Greenough, F.R.S.	W. Lonsdale, John Phillips.
1834. Edinburgh.	Prof. Jameson	Prof. Phillips, T. Jameson Torrie, Rev. J. Yates.

SECTION C.—GEOLOGY AND GEOGRAPHY.

1835. Dublin	R. J. Griffith	Captain Portlock, T. J. Torrie.
1836. Bristol	Rev. Dr. Buckland, F.R.S.—*Geography*, R. I. Murchison, F.R.S.	William Sanders, S. Stutchbury, T. J. Torrie.
1837. Liverpool...	Rev. Prof. Sedgwick, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	Captain Portlock, R. Hunter.—*Geography*, Captain H. M. Denham, R.N.

Date and Place	Presidents	Secretaries
1838. Newcastle..	C. Lyell, F.R.S., V.P.G.S.—*Geography*, Lord Prudhope.	W. C. Trevelyan, Capt. Portlock.—*Geography*, Capt. Washington.
1839. Birmingham	Rev. Dr. Buckland, F.R.S.—*Geography*, G.B.Greenough, F.R.S.	George Lloyd, M.D., H. E. Strickland, Charles Darwin.
1840. Glasgow ...	Charles Lyell, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	W. J. Hamilton, D. Milne, Hugh Murray, H. E. Strickland, John Scoular, M.D.
1841. Plymouth...	H. T. De la Beche, F.R.S. ...	W. J. Hamilton, Edward Moore, M.D., R. Hutton.
1842. Manchester	R. I. Murchison, F.R.S.	E. W. Binney, R. Hutton, Dr. R. Lloyd, H. E. Strickland.
1843. Cork.........	Richard E. Griffith, F.R.S., M.R.I.A.	Francis M. Jennings, H. E. Strickland.
1844. York.........	Henry Warburton, M.P., Pres. Geol. Soc.	Prof. Ansted, E. H. Bunbury.
1845. Cambridge.	Rev. Prof. Sedgwick, M.A., F.R.S.	Rev. J. C. Cumming, A. C. Ramsay, Rev. W. Thorp.
1846. Southampton.	Leonard Horner, F.R.S.—*Geography*, G. B. Greenough, F.R.S.	Robert A. Austen, Dr. J. H. Norton, Prof. Oldham.—*Geography*, Dr. C. T. Beke.
1847. Oxford......	Very Rev. Dr. Buckland, F.R.S.	Prof. Ansted, Prof. Oldham, A. C. Ramsay, J. Ruskin.
1848. Swansea ...	Sir H. T. De la Beche, C.B., F.R.S.	Starling Benson, Prof. Oldham, Prof. Ramsay.
1849. Birmingham	Sir Charles Lyell, F.R.S., F.G.S.	J. Beete Jukes, Prof. Oldham, Prof. A. C. Ramsay.
1850. Edinburgh[1]	Sir Roderick I. Murchison, F.R.S.	A. Keith Johnston, Hugh Miller, Prof. Nicol.

SECTION C (*continued*).—GEOLOGY.

1851. Ipswich ...	William Hopkins, M.A., F.R.S.	C. J. F. Bunbury, G. W. Ormerod, Searles Wood.
1852. Belfast......	Lieut.-Col. Portlock, R.E., F.R.S.	James Bryce, James MacAdam, Prof. M'Coy, Prof. Nicol.
1853. Hull	Prof. Sedgwick, F.R.S.........	Prof. Harkness, William Lawton.
1854. Liverpool..	Prof. Edward Forbes, F.R.S.	John Cunningham, Prof. Harkness, G. W. Ormerod, J. W. Woodall.
1855. Glasgow ...	Sir R. I. Murchison, F.R.S....	James Bryce, Prof. Harkness, Prof. Nicol.
1856. Cheltenham	Prof. A. C. Ramsay, F.R.S....	Rev. P. B. Brodie, Rev. R. Hepworth, Edward Hull, J. Scougall, T. Wright.
1857. Dublin......	The Lord Talbot de Malahide	Prof. Harkness, Gilbert Sanders, Robert H. Scott.
1858. Leeds	William Hopkins, M.A., LL.D., F.R.S.	Prof. Nicol, H. C. Sorby, E. W. Shaw.
1859. Aberdeen...	Sir Charles Lyell, LL.D., D.C.L., F.R.S.	Prof. Harkness, Rev. J. Longmuir, H. C. Sorby.
1860. Oxford......	Rev. Prof. Sedgwick, LL.D., F.R.S., F.G.S.	Prof. Harkness, Edward Hull, Capt. D. C. L. Woodall.
1861. Manchester	Sir R. I. Murchison, D.C.L., LL.D., F.R.S.	Prof. Harkness, Edward Hull, T. Rupert Jones, G. W. Ormerod.
1862. Cambridge	J. Beete Jukes, M.A., F.R.S.	Lucas Barrett, Prof. T. Rupert Jones, H. C. Sorby.

[1] At a meeting of the General Committee held in 1850, it was resolved 'That the subject of Geography be separated from Geology and combined with Ethnology, to constitute a separate Section, under the title of the "Geographical and Ethnological Section,"' for Presidents and Secretaries of which see page lii.

Date and Place	Presidents	Secretaries
1863. Newcastle	Prof. Warington W. Smyth, F.R.S., F.G.S.	E. F. Boyd, John Daglish, H. C. Sorby, Thomas Sopwith.
1864. Bath.........	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	W. B. Dawkins, J. Johnston, H. C. Sorby, W. Pengelly.
1865. Birmingham	Sir R. I. Murchison, Bart., K.C.B.	Rev. P. B. Brodie, J. Jones, Rev. E. Myers, H. C. Sorby, W. Pengelly.
1866. Nottingham	Prof. A. C. Ramsay, LL.D., F.R.S.	R. Etheridge, W. Pengelly, T. Wilson, G. H. Wright.
1867. Dundee ...	Archibald Geikie, F.R.S., F.G.S.	Edward Hull, W. Pengelly, Henry Woodward.
1868. Norwich ...	R. A. C. Godwin-Austen, F.R.S., F.G.S.	Rev. O. Fisher, Rev. J. Gunn, W. Pengelly, Rev. H. H. Winwood.
1869. Exeter	Prof. R. Harkness, F.R.S., F.G.S.	W. Pengelly, W. Boyd Dawkins, Rev. H. H. Winwood.
1870. Liverpool...	Sir Philip de M. Grey Egerton, Bart., M.P., F.R.S.	W. Pengelly, Rev. H. H. Winwood, W. Boyd Dawkins, G. H. Morton.
1871. Edinburgh	Prof. A. Geikie, F.R.S., F.G.S.	R. Etheridge, J. Geikie, T. McKenny Hughes, L. C. Miall.
1872. Brighton...	R. A. C. Godwin-Austen, F.R.S., F.G.S.	L. C. Miall, George Scott, William Topley, Henry Woodward.
1873. Bradford ...	Prof. J. Phillips, D.C.L., F.R.S., F.G.S.	L. C. Miall, R. H. Tiddeman, W. Topley.
1874. Belfast......	Prof. Hull, M.A., F.R.S., F.G.S.	F. Drew, L. C. Miall, R. G. Symes, R. H. Tiddeman.
1875. Bristol	Dr. Thomas Wright, F.R.S.E., F.G.S.	L. C. Miall, E. B. Tawney, W. Topley.
1876. Glasgow ..	Prof. John Young, M.D.	J. Armstrong, F. W. Rudler, W. Topley.
1877. Plymouth...	W. Pengelly, F.R.S...........	Dr. Le Neve Foster, R. H. Tiddeman, W. Topley.
1878. Dublin......	John Evans, D.C.L., F.R.S., F.S.A., F.G.S.	E. T. Hardman, Prof. J. O'Reilly, R. H. Tiddeman.
1879. Sheffield ...	Prof. P. Martin Duncan, M.B., F.R.S., F.G.S.	W. Topley, G. Blake Walker.
1880. Swansea ...	H. C. Sorby, LL.D., F.R.S., F.G.S.	W. Topley, W. Whitaker.
1881. York.........	A. C. Ramsay, LL.D., F.R.S., F.G.S.	J. E. Clark, W. Keeping, W. Topley, W. Whitaker.
1882. Southampton.	R. Etheridge, F.R.S., F.G.S.	T. W. Shore, W. Topley, E. Westlake, W. Whitaker.
1883. Southport	Prof. W. C. Williamson, LL.D., F.R.S.	R. Betley, C. E. De Rance, W. Topley, W. Whitaker.
1884. Montreal ...	W. T. Blanford, F.R.S., Sec. G.S.	F. Adams, Prof. E. W. Claypole, W. Topley, W. Whitaker.
1885. Aberdeen ...	Prof. J. W. Judd, F.R.S., Sec. G.S.	C. E. De Rance, J. Horne, J. J. H. Teall, W. Topley.

BIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, IV.—ZOOLOGY, BOTANY, PHYSIOLOGY, ANATOMY.

1832. Oxford......	Rev. P. B. Duncan, F.G.S. ...	Rev. Prof. J. S. Henslow.
1833. Cambridge[1]	Rev. W. L. P. Garnons, F.L.S.	C. C. Babington, D. Don.
1834. Edinburgh.	Prof. Graham.....................	W. Yarrell, Prof. Burnett.

[1] At this Meeting Physiology and Anatomy were made a separate Committee, for Presidents and Secretaries of which see p. li.

SECTION D.—ZOOLOGY AND BOTANY.

Date and Place	Presidents	Secretaries
1835. Dublin......	Dr. Allman........................	J. Curtis, Dr. Litton.
1836. Bristol......	Rev. Prof. Henslow	J. Curtis, Prof. Don, Dr. Riley, S. Rootsey.
1837. Liverpool...	W. S. MacLeay.................	C. C. Babington, Rev. L. Jenyns, W. Swainson.
1838. Newcastle	Sir W. Jardine, Bart.	J. E. Gray, Prof. Jones, R. Owen, Dr. Richardson.
1839. Birmingham	Prof. Owen, F.R.S.	E. Forbes, W. Ick, R. Patterson.
1840. Glasgow ...	Sir W. J. Hooker, LL.D.......	Prof. W. Couper, E. Forbes, R. Patterson.
1841. Plymouth...	John Richardson, M.D., F.R.S.	J. Couch, Dr. Lankester, R. Patterson.
1842. Manchester	Hon. and Very Rev. W. Herbert, LL.D., F.L.S.	Dr. Lankester, R. Patterson, J. A. Turner.
1843. Cork.........	William Thompson, F.L.S....	G. J. Allman, Dr. Lankester, R. Patterson.
1844. York.........	Very Rev. the Dean of Manchester.	Prof. Allman, H. Goodsir, Dr. King, Dr. Lankester.
1845. Cambridge	Rev. Prof. Henslow, F.L.S....	Dr. Lankester, T. V. Wollaston.
1846. Southampton.	Sir J. Richardson, M.D., F.R.S.	Dr. Lankester, T. V. Wollaston, H. Wooldridge.
1847. Oxford......	H. E. Strickland, M.A., F.R.S.	Dr. Lankester, Dr. Melville, T. V. Wollaston.

SECTION D (*continued*).—ZOOLOGY AND BOTANY, INCLUDING PHYSIOLOGY.

[For the Presidents and Secretaries of the Anatomical and Physiological Subsections and the temporary Section E of Anatomy and Medicine, see p. li.]

1848. Swansea ...	L. W. Dillwyn, F.R.S.........	Dr. R. Wilbraham Falconer, A. Henfrey, Dr. Lankester.
1849. Birmingham	William Spence, F.R.S.	Dr. Lankester, Dr. Russell.
1850. Edinburgh	Prof. Goodsir, F.R.S. L. & E.	Prof. J. H. Bennett, M.D., Dr. Lankester, Dr. Douglas Maclagan.
1851. Ipswich ...	Rev. Prof. Henslow, M.A., F.R.S.	Prof. Allman, F. W. Johnston, Dr. E. Lankester.
1852. Belfast......	W. Ogilby	Dr. Dickie, George C. Hyndman, Dr. Edwin Lankester.
1853. Hull.........	C. C. Babington, M.A., F.R.S.	Robert Harrison, Dr. E. Lankester.
1854. Liverpool...	Prof. Balfour, M.D., F.R.S....	Isaac Byerley, Dr. E. Lankester.
1855. Glasgow ...	Rev. Dr. Fleeming, F.R.S.E.	William Keddie, Dr. Lankester.
1856. Cheltenham	Thomas Bell, F.R.S., Pres.L.S.	Dr. J. Abercrombie, Prof. Buckman, Dr. Lankester.
1857. Dublin......	Prof. W. H. Harvey, M.D., F.R.S.	Prof. J. R. Kinahan, Dr. E. Lankester, Robert Patterson, Dr. W. E. Steele.
1858. Leeds	C. C. Babington, M.A., F.R.S.	Henry Denny, Dr. Heaton, Dr. E. Lankester, Dr. E. Perceval Wright.
1859. Aberdeen...	Sir W. Jardine, Bart., F.R.S.E.	Prof. Dickie, M.D., Dr. E. Lankester, Dr. Ogilvy.
1860. Oxford......	Rev. Prof. Henslow, F.L.S....	W. S. Church, Dr. E. Lankester, P. L. Sclater, Dr. E. Perceval Wright.
1861. Manchester	Prof. C. C. Babington, F.R.S.	Dr. T. Alcock, Dr. E. Lankester, Dr. P. L. Sclater, Dr. E. P. Wright.
1862. Cambridge	Prof. Huxley, F.R.S.	Alfred Newton, Dr. E. P. Wright.
1863. Newcastle	Prof. Balfour, M.D., F.R.S....	Dr. E. Charlton, A. Newton, Rev. H. B. Tristram, Dr. E. P. Wright.
1864. Bath.........	Dr. John E. Gray, F.R.S. ...	H. B. Brady, C. E. Broom, H. T. Stainton, Dr. E. P. Wright.
1865. Birmingham	T. Thomson, M.D., F.R.S. ...	Dr. J. Anthony, Rev. C. Clarke, Rev. H. B. Tristram, Dr. E. P. Wright.

SECTION D (*continued*).—BIOLOGY.[1]

Date and Place	Presidents	Secretaries
1866. Nottingham	Prof. Huxley, LL.D., F.R.S. —*Physiological Dep.*, Prof. Humphry, M.D., F.R.S.—*Anthropological Dep.*, Alf. R. Wallace, F.R.G.S.	Dr. J. Beddard, W. Felkin, Rev. H. B. Tristram, W. Turner, E. B. Tylor, Dr. E. P. Wright.
1867. Dundee ...	Prof. Sharpey, M.D., Sec. R.S. —*Dep. of Zool. and Bot.*, George Busk, M.D., F.R.S.	C. Spence Bate, Dr. S. Cobbold, Dr. M. Foster, H. T. Stainton, Rev. H. B. Tristram, Prof. W. Turner.
1868. Norwich ...	Rev. M. J. Berkeley, F.L.S. —*Dep. of Physiology*, W. H. Flower, F.R.S.	Dr. T. S. Cobbold, G. W. Firth, Dr. M. Foster, Prof. Lawson, H. T. Stainton, Rev. Dr. H. B. Tristram, Dr. E. P. Wright.
1869. Exeter	George Busk, F.R.S., F.L.S. —*Dep. of Bot. and Zool.*, C. Spence Bate, F.R.S.—*Dep. of Ethno.*, E. B. Tylor.	Dr. T. S. Cobbold, Prof. M. Foster, E. Ray Lankester, Prof. Lawson, H. T Stainton, Rev. H. B. Tristram.
1870. Liverpool...	Prof. G. Rolleston, M.A., M.D., F.R.S., F.L.S.—*Dep. of Anat. and Physiol.*, Prof. M. Foster, M.D., F.L.S.—*Dep. of Ethno.*, J. Evans, F.R.S.	Dr. T. S. Cobbold, Sebastian Evans, Prof. Lawson, Thos. J. Moore, H. T. Stainton, Rev. H. B. Tristram, C. Staniland Wake, E. Ray Lankester.
1871. Edinburgh	Prof. Allen Thomson, M.D., F.R.S.—*Dep. of Bot. and Zool.*, Prof. Wyville Thomson, F.R.S.—*Dep. of Anthropol.*, Prof. W. Turner, M.D.	Dr. T. R. Fraser, Dr. Arthur Gamgee, E. Ray Lankester, Prof. Lawson, H. T. Stainton, C. Staniland Wake, Dr. W. Rutherford, Dr. Kelburne King.
1872. Brighton ...	Sir J. Lubbock, Bart., F.R.S.—*Dep. of Anat. and Physiol.*, Dr. Burdon Sanderson, F.R.S.—*Dep. of Anthropol.*, Col. A. Lane Fox, F.G.S.	Prof. Thiselton-Dyer, H. T. Stainton, Prof. Lawson, F. W. Rudler, J. H. Lamprey, Dr. Gamgee, E. Ray Lankester, Dr. Pye-Smith.
1873. Bradford ...	Prof. Allman, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Rutherford, M.D.—*Dep. of Anthropol.*, Dr. Beddoe, F.R.S.	Prof. Thiselton-Dyer, Prof. Lawson, R. M'Lachlan, Dr. Pye-Smith, E. Ray Lankester, F. W. Rudler, J. H. Lamprey.
1874. Belfast	Prof. Redfern, M.D.—*Dep. of Zool. and Bot.*, Dr. Hooker, C.B., Pres. R.S.—*Dep. of Anthrop.*, Sir W. R. Wilde, M.D.	W. T. Thiselton-Dyer, R. O. Cunningham, Dr. J. J. Charles, Dr. P. H. Pye-Smith, J. J. Murphy, F. W. Rudler.
1875. Bristol	P. L. Sclater, F.R.S.—*Dep. of Anat. and Physiol.*, Prof. Cleland, M.D., F.R.S.—*Dep. of Anthropol.*, Prof. Rolleston, M.D., F.R.S.	E. R. Alston, Dr. McKendrick, Prof. W. R. M'Nab, Dr. Martyn, F. W. Rudler, Dr. P. H. Pye-Smith, Dr. W. Spencer.
1876. Glasgow ...	A. Russel Wallace, F.R.G.S., F.L.S.—*Dep. of Zool. and Bot.*, Prof. A. Newton, M.A., F.R.S.—*Dep. of Anat. and Physiol.*, Dr. J. G. McKendrick, F.R.S.E.	E. R. Alston, Hyde Clarke, Dr. Knox, Prof. W. R. M'Nab, Dr. Muirhead, Prof. Morrison Watson.
1877. Plymouth...	J. Gwyn Jeffreys, LL.D., F.R.S., F.L.S.—*Dep. of Anat. and Physiol.*, Prof. Macalister, M.D.—*Dep. of Anthropol.*, Francis Galton, M.A., F.R.S.	E. R. Alston, F. Brent, Dr. D. J Cunningham, Dr. C. A. Hingston, Prof. W. R. M'Nab, J. B. Rowe, F. W. Rudler.

[1] At a meeting of the General Committee in 1865, it was resolved:—'That the title of Section D be changed to Biology;' and 'That for the word "Subsection," in the rules for conducting the business of the Sections, the word "Department" be substituted.'

Date and Place	Presidents	Secretaries
1878. Dublin	Prof. W. H. Flower, F.R.S.—*Dep. of Anthropol.*, Prof. Huxley, Sec. R.S.—*Dep. of Anat. and Physiol.*, R. McDonnell, M.D., F.R.S.	Dr. R. J. Harvey, Dr. T. Hayden, Prof. W. R. M'Nab, Prof. J. M. Purser, J. B. Rowe, F. W. Rudler.
1879. Sheffield ...	Prof. St. George Mivart, F.R.S.—*Dep. of Anthropol.*, E. B. Tylor, D.C.L., F.R.S. —*Dep. of Anat. and Physiol.*, Dr. Pye-Smith.	Arthur Jackson, Prof. W. R. M'Nab, J. B. Rowe, F. W. Rudler, Prof. Schäfer.
1880. Swansea ...	A. C. L. Günther, M.D., F.R.S. —*Dep. of Anat. and Physiol.*, F. M. Balfour, M.A., F.R.S.—*Dep. of Anthropol.*, F. W. Rudler, F.G.S.	G. W. Bloxam, John Priestley, Howard Saunders, Adam Sedgwick.
1881. York.........	Richard Owen, C.B., M.D., F.R.S.—*Dep. of Anthropol.*, Prof. W. H. Flower, LL.D., F.R.S.—*Dep. of Anat. and Physiol.*, Prof. J. S. Burdon Sanderson, M.D., F.R.S.	G. W. Bloxam, W. A. Forbes, Rev. W. C. Hey, Prof. W. R. M'Nab, W. North, John Priestley, Howard Saunders, H. E. Spencer.
1882. Southampton.	Prof. A. Gamgee, M.D., F.R.S. —*Dep. of Zool. and Bot.*, Prof. M. A. Lawson, M.A., F.L.S.—*Dep. of Anthropol.*, Prof. W. Boyd Dawkins, M.A., F.R.S.	G. W. Bloxam, W. Heape, J. B. Nias, Howard Saunders, A. Sedgwick, T. W. Shore, jun.
1883. Southport [1]	Prof. E. Ray Lankester, M.A., F.R.S.—*Dep. of Anthropol.*, W. Pengelly, F.R.S.	G. W. Bloxam, Dr. G. J. Haslam, W. Heape, W. Hurst, Prof. A. M. Marshall, Howard Saunders, Dr. G. A. Woods.
1884. Montreal [2]...	Prof. H. N. Moseley, M.A., F.R.S.	Prof. W. Osler, Howard Saunders, A. Sedgwick, Prof. R. R. Wright.
1885. Aberdeen ...	Prof. W. C. McIntosh, M.D., LL.D., F.R.S. L. & E.	W. Heape, J. McGregor-Robertson, J. Duncan Matthews, Howard Saunders, H. Marshall Ward.

ANATOMICAL AND PHYSIOLOGICAL SCIENCES.

COMMITTEE OF SCIENCES, V.—ANATOMY AND PHYSIOLOGY.

1833. Cambridge	Dr. Haviland	Dr. Bond, Mr. Paget.
1834. Edinburgh	Dr. Abercrombie	Dr. Roget, Dr. William Thomson.

SECTION E (UNTIL 1847).—ANATOMY AND MEDICINE.

1835. Dublin	Dr. Pritchard......................	Dr. Harrison, Dr. Hart.
1836. Bristol	Dr. Roget, F.R.S.	Dr. Symonds.
1837. Liverpool...	Prof. W. Clark, M.D.	Dr. J. Carson, jun., James Long, Dr. J. R. W. Vose.
1838. Newcastle	T. E. Headlam, M.D.	T. M. Greenhow, Dr. J. R. W. Vose.
1839. Birmingham	John Yelloly, M.D., F.R.S....	Dr. G. O. Rees, F. Ryland.
1840. Glasgow ...	James Watson, M.D.	Dr. J. Brown, Prof. Couper, Prof. Reid.
1841. Plymouth...	P. M. Roget, M.D., Sec. R.S.	Dr. J. Butter, J. Fuge, Dr. R. S Sargent.

[1] By direction of the General Committee at Southampton (1882) the Departments of Zoology and Botany and of Anatomy and Physiology were amalgamated.

[2] By authority of the General Committee, Anthropology was made a separate Section, for Presidents and Secretaries of which see p. lvii.

SECTION E.—PHYSIOLOGY.

Date and Place	Presidents	Secretaries
1842. Manchester	Edward Holme, M.D., F.L.S.	Dr. Chaytor, Dr. R. S. Sargent.
1843. Cork	Sir James Pitcairn, M.D. ...	Dr. John Popham, Dr. R. S. Sargent.
1844 York	J. C. Pritchard, M.D.	I. Erichsen, Dr. R. S. Sargent.
1845. Cambridge	Prof. J. Haviland, M.D.	Dr. R. S. Sargent, Dr. Webster.
1846. Southampton.	Prof. Owen, M.D., F.R.S. ...	C. P. Keele, Dr. Laycock, Dr. Sargent.
1847. Oxford[1] ...	Prof. Ogle, M.D., F.R.S.	Dr. Thomas K. Chambers, W. P. Ormerod.

PHYSIOLOGICAL SUBSECTIONS OF SECTION D.

1850. Edinburgh	Prof. Bennett, M.D., F.R.S.E.	
1855. Glasgow ...	Prof. Allen Thomson, F.R.S.	Prof. J. H. Corbett, Dr. J. Struthers.
1857. Dublin......	Prof. R. Harrison, M.D.	Dr. R. D. Lyons, Prof. Redfern.
1858. Leeds	Sir Benjamin Brodie, Bart., F.R.S.	C. G. Wheelhouse.
1859. Aberdeen...	Prof. Sharpey, M.D., Sec.R.S.	Prof. Bennett, Prof. Redfern.
1860. Oxford......	Prof. G. Rolleston, M.D., F.L.S.	Dr. R. M'Donnell, Dr. Edward Smith.
1861. Manchester	Dr. John Davy, F.R.S.L.& E.	Dr. W. Roberts, Dr. Edward Smith.
1862. Cambridge	G. E. Paget, M.D...............	G. F. Helm, Dr. Edward Smith.
1863. Newcastle	Prof. Rolleston, M.D., F.R.S.	Dr. D. Embleton, Dr. W. Turner.
1864. Bath.........	Dr. Edward Smith, LL.D., F.R.S.	J. S. Bartrum, Dr. W. Turner.
1865. Birmingham.[2]	Prof. Acland, M.D., LL.D., F.R.S.	Dr. A. Fleming, Dr. P. Heslop, Oliver Pembleton, Dr. W. Turner.

GEOGRAPHICAL AND ETHNOLOGICAL SCIENCES.

[For Presidents and Secretaries for Geography previous to 1851, see Section C, p. xlvi.]

ETHNOLOGICAL SUBSECTIONS OF SECTION D.

1846. Southampton	Dr. Pritchard.....................	Dr. King.
1847. Oxford	Prof. H. H. Wilson, M.A. ...	Prof. Buckley.
1848. Swansea ...	....	G. Grant Francis.
1849. Birmingham	....	Dr. R. G. Latham.
1850. Edinburgh	Vice-Admiral Sir A. Malcolm	Daniel Wilson.

SECTION E.—GEOGRAPHY AND ETHNOLOGY.

1851. Ipswich ...	Sir R. I. Murchison, F.R.S., Pres. R.G.S.	R. Cull, Rev. J. W. Donaldson, Dr. Norton Shaw.
1852. Belfast......	Col. Chesney, R.A., D.C.L., F.R.S.	R. Cull, R. MacAdam, Dr. Norton Shaw.
1853. Hull	R. G. Latham, M.D., F.R.S.	R. Cull, Rev. H. W. Kemp, Dr. Norton Shaw.
1854. Liverpool...	Sir R. I. Murchison, D.C.L., F.R.S.	Richard Cull, Rev. H. Higgins, Dr. Ihne, Dr. Norton Shaw.
1855. Glasgow ...	Sir J. Richardson, M.D., F.R.S.	Dr. W. G. Blackie, R. Cull, Dr. Norton Shaw.
1856. Cheltenham	Col. Sir H. C. Rawlinson, K.C.B.	R. Cull, F. D. Hartland, W. H. Rumsey, Dr. Norton Shaw.
1857. Dublin......	Rev. Dr. J. Henthorn Todd, Pres. R.I.A.	R. Cull, S. Ferguson, Dr. R. R. Madden, Dr. Norton Shaw.

[1] By direction of the General Committee at Oxford, Sections D and E were incorporated under the name of 'Section D—Zoology and Botany, including Physiology' (see p. xlix). The Section being then vacant was assigned in 1851 to Geography.

[2] *Vide* note on page l.

Date and Place	Presidents	Secretaries
1858. Leeds	Sir R. I. Murchison, G.C.St.S., F.R.S.	R. Cull, Francis Galton, P. O'Callaghan, Dr. Norton Shaw, Thomas Wright.
1859. Aberdeen...	Rear-Admiral Sir James Clerk Ross, D.C.L., F.R.S.	Richard Cull, Prof. Geddes, Dr. Norton Shaw.
1860. Oxford	Sir R. I. Murchison, D.C.L., F.R.S.	Capt. Burrows, Dr. J. Hunt, Dr. C. Lemprière, Dr. Norton Shaw.
1861. Manchester	John Crawfurd, F.R.S..........	Dr. J. Hunt, J. Kingsley, Dr. Norton Shaw, W. Spottiswoode.
1862. Cambridge	Francis Galton, F.R.S..........	J. W. Clarke, Rev. J. Glover, Dr. Hunt, Dr. Norton Shaw, T. Wright.
1863. Newcastle	Sir R. I. Murchison, K.C.B., F.R.S.	C. Carter Blake, Hume Greenfield, C. R. Markham, R. S. Watson.
1864. Bath.........	Sir R. I. Murchison, K.C.B., F.R.S.	H. W. Bates, C. R. Markham, Capt. R. M. Murchison, T. Wright.
1865. Birmingham	Major-General Sir H. Rawlinson, M.P., K.C.B., F.R.S.	H. W. Bates, S. Evans, G. Jabet, C. R. Markham, Thomas Wright.
1866. Nottingham	Sir Charles Nicholson, Bart., LL.D.	H. W. Bates, Rev. E. T. Cusins, R. H. Major, Clements R. Markham, D. W. Nash, T. Wright.
1867. Dundee ...	Sir Samuel Baker, F.R.G.S.	H. W. Bates, Cyril Graham, Clements R. Markham, S. J. Mackie, R. Sturrock.
1868. Norwich ...	Capt. G. H. Richards, R.N., F.R.S.	T. Baines, H. W. Bates, Clements R. Markham, T. Wright.

SECTION E (*continued*).—GEOGRAPHY.

Date and Place	Presidents	Secretaries
1869. Exeter	Sir Bartle Frere, K.C.B., LL.D., F.R.G.S.	H. W. Bates, Clements R. Markham, J. H. Thomas.
1870. Liverpool...	Sir R. I. Murchison, Bt., K.C.B., LL.D., D.C.L., F.R.S., F.G.S.	H. W. Bates, David Buxton, Albert J. Mott, Clements R. Markham.
1871. Edinburgh	Colonel Yule, C.B., F.R.G.S.	Clements R. Markham, A. Buchan, J. H. Thomas, A. Keith Johnston.
1872. Brighton ...	Francis Galton, F.R.S..........	H. W. Bates, A. Keith Johnston, Rev. J. Newton, J. H. Thomas.
1873. Bradford ...	Sir Rutherford Alcock, K.C.B.	H. W. Bates, A. Keith Johnston, Clements R. Markham.
1874. Belfast......	Major Wilson, R.E., F.R.S., F.R.G.S.	E. G. Ravenstein, E. C. Rye, J. H. Thomas.
1875. Bristol	Lieut.-General Strachey, R.E., C.S.I., F.R.S., F.R.G.S., F.L.S., F.G.S.	H. W. Bates, E. C. Rye, F. F. Tuckett.
1876. Glasgow ...	Capt. Evans, C.B., F.R.S.......	H. W. Bates, E. C. Rye, R. Oliphant Wood.
1877. Plymouth...	Adm. Sir E. Ommanney, C.B., F.R.S., F.R.G.S., F.R.A.S.	H. W. Bates, F. E. Fox, E. C. Rye.
1878. Dublin......	Prof. Sir C. Wyville Thomson, LL.D., F.R.S.L.&E.	John Coles, E. C. Rye.
1879. Sheffield ...	Clements R. Markham, C.B., F.R.S., Sec. R.G.S.	H. W. Bates, C. E. D. Black, E. C. Rye.
1880. Swansea ...	Lieut.-Gen. Sir J. H. Lefroy, C.B., K.C.M.G., R.A., F.R.S., F.R.G.S.	H. W. Bates, E. C. Rye.
1881. York.........	Sir J. D. Hooker, K.C.S.I., C.B., F.R.S.	J. W. Barry, H. W. Bates.
1882. Southampton.	Sir R. Temple, Bart., G.C.S.I., F.R.G.S.	E. G. Ravenstein, E. C. Rye.

Date and Place	Presidents	Secretaries
1883. Southport	Lieut.-Col. H. H. Godwin-Austen, F.R.S.	John Coles, E. G. Ravenstein, E. C. Rye.
1884. Montreal ...	Gen. Sir J. H. Lefroy, C.B., K.C.M.G., F.R.S., V.P.R.G.S.	Rev. Abbé Laflamme, J. S. O'Halloran, E. G. Ravenstein, J. F. Torrance
1885. Aberdeen...	Gen. J. T. Walker, C.B., R.E., LL.D., F.R.S.	J. S. Keltie, J. S. O'Halloran, E. G. Ravenstein, Rev. G. A. Smith.

STATISTICAL SCIENCE.

COMMITTEE OF SCIENCES, VI.—STATISTICS.

1833. Cambridge	Prof. Babbage, F.R.S.	J. E. Drinkwater.
1834. Edinburgh	Sir Charles Lemon, Bart.......	Dr. Cleland, C. Hope Maclean.

SECTION F.—STATISTICS.

1835. Dublin	Charles Babbage, F.R.S.	W. Greg, Prof. Longfield.
1836. Bristol	Sir Chas. Lemon, Bart., F.R.S.	Rev. J. E. Bromby, C. B. Fripp, James Heywood.
1837. Liverpool...	Rt. Hon. Lord Sandon	W. R. Greg, W. Langton, Dr. W. C. Tayler.
1838. Newcastle	Colonel Sykes, F.R.S.	W. Cargill, J. Heywood, W. R. Wood.
1839. Birmingham	Henry Hallam, F.R.S.	F. Clarke, R. W. Rawson, Dr. W. C. Tayler.
1840. Glasgow ...	Rt. Hon. Lord Sandon, M.P., F.R.S.	C. R. Baird, Prof. Ramsay, R. W. Rawson.
1841 Plymouth...	Lieut.-Col. Sykes, F.R.S.......	Rev. Dr. Byrth, Rev. R. Luney, R. W. Rawson.
1842. Manchester	G. W. Wood, M.P., F.L.S. ...	Rev. R. Luney, G. W. Ormerod, Dr. W. C. Tayler.
1843. Cork	Sir C. Lemon, Bart., M.P. ...	Dr. D. Bullen, Dr. W. Cooke Tayler.
1844. York.........	Lieut.-Col. Sykes, F.R.S., F.L.S.	J. Fletcher, J. Heywood, Dr. Laycock.
1845. Cambridge	Rt. Hon. the Earl Fitzwilliam	J. Fletcher, Dr. W. Cooke Tayler.
1846. Southampton.	G. R. Porter, F.R.S.	J. Fletcher, F. G. P. Neison, Dr. W. C. Tayler, Rev. T. L. Shapcott.
1847. Oxford	Travers Twiss, D.C.L., F.R.S.	Rev. W. H. Cox, J. J. Danson, F. G. P. Neison.
1848. Swansea ...	J. H. Vivian, M.P., F.R.S. ...	J. Fletcher, Capt. R. Shortrede.
1849. Birmingham	Rt. Hon. Lord Lyttelton......	Dr. Finch, Prof. Hancock, F. G. P. Neison.
1850. Edinburgh	Very Rev. Dr. John Lee, V.P.R.S.E.	Prof. Hancock, J. Fletcher, Dr. J. Stark.
1851. Ipswich ...	Sir John P. Boileau, Bart. ...	J. Fletcher, Prof. Hancock.
1852. Belfast......	His Grace the Archbishop of Dublin.	Prof. Hancock, Prof. Ingram, James MacAdam, jun.
1853. Hull	James Heywood, M.P., F.R.S.	Edward Cheshire, W. Newmarch.
1854. Liverpool...	Thomas Tooke, F.R.S.	E. Cheshire, J. T. Danson, Dr. W. H. Duncan, W. Newmarch.
1855. Glasgow ...	R. Monckton Milnes, M.P. ...	J. A. Campbell, E. Cheshire, W. Newmarch, Prof. R. H. Walsh.

SECTION F (*continued*).—ECONOMIC SCIENCE AND STATISTICS.

1856. Cheltenham	Rt. Hon. Lord Stanley, M.P.	Rev. C. H. Bromby, E. Cheshire, Dr W. N. Hancock, W. Newmarch, W. M. Tartt.
1857. Dublin	His Grace the Archbishop of Dublin, M.R.I.A.	Prof. Cairns, Dr. H. D. Hutton, W. Newmarch.

Date and Place	Presidents	Secretaries
1858. Leeds	Edward Baines	T. B. Baines, Prof. Cairns, S. Brown, Capt. Fishbourne, Dr. J. Strang.
1859. Aberdeen...	Col. Sykes, M.P., F.R.S.	Prof. Cairns, Edmund Macrory, A. M. Smith, Dr. John Strang.
1860. Oxford......	Nassau W. Senior, M.A.	Edmund Macrory, W. Newmarch, Rev. Prof. J. E. T. Rogers.
1861. Manchester	William Newmarch, F.R.S....	David Chadwick, Prof. R. C. Christie, E. Macrory, Rev. Prof. J. E. T. Rogers.
1862. Cambridge	Edwin Chadwick, C.B.	H. D. Macleod, Edmund Macrory.
1863. Newcastle .	William Tite, M.P., F.R.S. ...	T. Doubleday, Edmund Macrory Frederick Purdy, James Potts.
1864. Bath	William Farr, M.D., D.C.L., F.R.S.	E. Macrory, E. T. Payne, F. Purdy.
1865. Birmingham	Rt. Hon. Lord Stanley, LL.D., M.P.	G. J. D. Goodman, G. J. Johnston, E. Macrory.
1866. Nottingham	Prof. J. E. T. Rogers............	R. Birkin, jun., Prof. Leone Levi, E. Macrory.
1867. Dundee	M. E. Grant Duff, M.P.	Prof. Leone Levi, E. Macrory, A. J. Warden.
1868. Norwich	Samuel Brown, Pres. Instit. Actuaries.	Rev. W. C. Davie, Prof. Leone Levi.
1869. Exeter	Rt. Hon. Sir Stafford H. Northcote, Bart., C.B., M.P.	Edmund Macrory, Frederick Purdy, Charles T. D. Acland.
1870. Liverpool...	Prof. W. Stanley Jevons, M.A.	Chas. R. Dudley Baxter, E. Macrory, J. Miles Moss.
1871. Edinburgh	Rt. Hon. Lord Neaves	J. G. Fitch, James Meikle.
1872. Brighton ...	Prof. Henry Fawcett, M.P. ...	J. G. Fitch, Barclay Phillips.
1873. Bradford ...	Rt. Hon. W. E. Forster, M.P.	J. G. Fitch, Swire Smith.
1874. Belfast......	Lord O'Hagan	Prof. Donnell, Frank P. Fellows, Hans MacMordie.
1875. Bristol	James Heywood, M.A., F.R.S., Pres.S.S.	F. P. Fellows, T. G. P. Hallett, E. Macrory.
1876. Glasgow ...	Sir George Campbell, K.C.S.I., M.P.	A. M'Neel Caird, T. G. P. Hallett, Dr. W. Neilson Hancock, Dr. W. Jack.
1877. Plymouth...	Rt. Hon. the Earl Fortescue	W. F. Collier, P. Hallett, J. T. Pim.
1878. Dublin	Prof. J. K. Ingram, LL.D., M.R.I.A.	W. J. Hancock, C. Molloy, J. T. Pim.
1879. Sheffield ...	G. Shaw Lefevre, M.P., Pres. S.S.	Prof. Adamson, R. E. Leader, C. Molloy.
1880. Swansea ...	G. W. Hastings, M.P.	N. A. Humphreys, C. Molloy.
1881. York.........	Rt. Hon. M. E. Grant-Duff, M.A., F.R.S.	C. Molloy, W. W. Morrell, J. F. Moss.
1882. Southampton.	Rt. Hon. G. Sclater-Booth, M.P., F.R.S.	G. Baden-Powell, Prof. H. S. Foxwell, A. Milnes, C. Molloy.
1883. Southport	R. H. Inglis Palgrave, F.R.S.	Rev. W. Cunningham, Prof. H. S. Foxwell, J. N. Keynes, C. Molloy.
1884. Montreal ...	Sir Richard Temple, Bart., G.C.S.I., C.I.E., F.R.G.S.	Prof. H. S. Foxwell, J. S. McLennan, Prof. J. Watson.
1885. Aberdeen...	Prof. H. Sidgwick, LL.D., Litt.D.	Rev. W. Cunningham, Prof. H. S. Foxwell, C. McCombie, J. F. Moss.

MECHANICAL SCIENCE.

SECTION G.—MECHANICAL SCIENCE.

1836. Bristol......	Davies Gilbert, D.C.L., F.R.S.	T. G. Bunt, G. T. Clark, W. West.
1837. Liverpool...	Rev. Dr. Robinson	Charles Vignoles, Thomas Webster.
1838. Newcastle	Charles Babbage, F.R.S.	R. Hawthorn, C. Vignoles, T. Webster.

Date and Place	Presidents	Secretaries
1839. Birmingham	Prof. Willis, F.R.S., and Robt. Stephenson.	W. Carpmael, William Hawkes, T. Webster.
1840. Glasgow	Sir John Robinson	J. Scott Russell, J. Thomson, J. Tod, C. Vignoles.
1841. Plymouth	John Taylor, F.R.S.	Henry Chatfield, Thomas Webster.
1842. Manchester	Rev. Prof. Willis, F.R.S.	J. F. Bateman, J. Scott Russell, J. Thomson, Charles Vignoles.
1843. Cork	Prof. J. Macneill, M.R.I.A. ...	James Thomson, Robert Mallet.
1844. York	John Taylor, F.R.S.	Charles Vignoles, Thomas Webster.
1845. Cambridge	George Rennie, F.R.S..........	Rev. W. T. Kingsley.
1846. Southampton.	Rev. Prof. Willis, M.A., F.R.S.	William Betts, jun., Charles Manby.
1847. Oxford	Rev. Prof. Walker, M.A., F.R.S.	J. Glynn, R. A. Le Mesurier.
1848. Swansea ...	Rev. Prof. Walker, M.A., F.R.S.	R. A. Le Mesurier, W. P. Struvé.
1849. Birmingham	Robert Stephenson, M.P., F.R.S.	Charles Manby, W. P. Marshall.
1850. Edinburgh	Rev. R. Robinson	Dr. Lees, David Stephenson.
1851. Ipswich	William Cubitt, F.R.S..........	John Head, Charles Manby.
1852. Belfast	John Walker, C.E., LL.D., F.R.S.	John F. Bateman, C. B Hancock, Charles Manby, James Thomson.
1853. Hull	William Fairbairn, C.E., F.R.S.	James Oldham, J. Thomson, W. Sykes Ward.
1854. Liverpool...	John Scott Russell, F.R.S. ...	John Grantham, J. Oldham, J. Thomson.
1855. Glasgow ...	W. J. Macquorn Rankine, C.E., F.R.S.	L. Hill, jun., William Ramsay, J. Thomson.
1856. Cheltenham	George Rennie, F.R.S.	C. Atherton, B. Jones, jun., H. M. Jeffery.
1857. Dublin......	Rt. Hon. the Earl of Rosse, F.R.S.	Prof. Downing, W.T. Doyne, A. Tate, James Thomson, Henry Wright.
1858. Leeds	William Fairbairn, F.R.S. ...	J. C. Dennis, J. Dixon, H. Wright.
1859. Aberdeen...	Rev. Prof. Willis, M.A., F.R.S.	R. Abernethy, P. Le Neve Foster, H. Wright.
1860. Oxford	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, Rev. F. Harrison, Henry Wright.
1861. Manchester	J. F. Bateman, C.E., F.R.S....	P. Le Neve Foster, John Robinson, H. Wright.
1862. Cambridge	Wm. Fairbairn, LL.D., F.R.S.	W. M. Fawcett, P. Le Neve Foster.
1863. Newcastle	Rev. Prof. Willis, M.A., F.R.S.	P. Le Neve Foster, P. Westmacott, J. F. Spencer.
1864. Bath	J. Hawkshaw, F.R.S.	P. Le Neve Foster, Robert Pitt.
1865. Birmingham	Sir W. G. Armstrong, LL.D., F.R.S.	P. Le Neve Foster, Henry Lea, W. P. Marshall, Walter May.
1866. Nottingham	Thomas Hawksley, V.P.Inst. C.E., F.G.S.	P. Le Neve Foster, J. F. Iselin, M. O. Tarbotton.
1867. Dundee......	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	P. Le Neve Foster, John P. Smith, W. W. Urquhart.
1868. Norwich ...	G. P. Bidder, C.E., F.R.G.S.	P. Le Neve Foster, J. F. Iselin, C. Manby, W. Smith.
1869. Exeter	C. W. Siemens, F.R.S.........	P. Le Neve Foster, H. Bauerman.
1870. Liverpool...	Chas. B. Vignoles, C.E., F.R.S.	H. Bauerman, P. Le Neve Foster, T. King, J. N. Shoolbred.
1871. Edinburgh	Prof. Fleeming Jenkin, F.R.S.	H. Bauerman, Alexander Leslie, J. P. Smith.
1872. Brighton ...	F. J. Bramwell, C.E.	H. M. Brunel, P. Le Neve Foster, J. G. Gamble, J. N. Shoolbred.
1873. Bradford ...	W. H. Barlow, F.R.S.	Crawford Barlow, H. Bauerman, E. H. Carbutt, J. C. Hawkshaw, J. N. Shoolbred.
1874. Belfast	Prof. James Thomson, LL.D., C.E., F.R.S.E.	A. T. Atchison, J. N. Shoolbred, John Smyth, jun.

Date and Place	Presidents	Secretaries
1875. Bristol	W. Froude, C.E., M.A., F.R.S.	W. R. Browne, H. M. Brunel, J. G. Gamble, J. N. Shoolbred.
1876. Glasgow ...	C. W. Merrifield, F.R.S.	W. Bottomley, jun., W. J. Millar, J. N. Shoolbred, J. P. Smith.
1877. Plymouth...	Edward Woods, C.E.	A. T. Atchison, Dr. Merrifield, J. N. Shoolbred.
1878. Dublin	Edward Easton, C.E.	A. T. Atchison, R. G. Symes, H. T. Wood.
1879. Sheffield ...	J. Robinson, Pres. Inst. Mech. Eng.	A. T. Atchison, Emerson Bainbridge, H. T. Wood.
1880. Swansea ...	James Abernethy, V.P. Inst. C.E., F.R.S.E.	A. T. Atchison, H. T. Wood.
1881. York.........	Sir W. G. Armstrong, C.B., LL.D., D.C.L., F.R.S.	A. T. Atchison, J. F. Stephenson, H. T. Wood.
1882. Southampton.	John Fowler, C.E., F.G.S. ...	A. T. Atchison, F. Churton, H. T. Wood.
1883. Southport	James Brunlees, F.R.S.E., Pres.Inst.C.E.	A. T. Atchison, E. Rigg, H. T. Wood.
1884. Montreal ...	Sir F. J. Bramwell, F.R.S., V.P.Inst.C.E.	A. T. Atchison, W. B. Dawson, J. Kennedy, H. T. Wood.
1885. Aberdeen...	B. Baker, M.Inst.C.E.	A. T. Atchison, F. G. Ogilvie, E. Rigg, J. N. Shoolbred.

ANTHROPOLOGICAL SCIENCE.

SECTION H.—ANTHROPOLOGY.

1884. Montreal ...	E. B. Tylor, D.C.L., F.R.S. ...	G. W. Bloxam, W. Hurst.
1885. Aberdeen...	Francis Galton, M.A., F.R.S.	G. W. Bloxam, Dr. J. G. Garson, W. Hurst, Dr. A. Macgregor.

LIST OF EVENING LECTURES.

Date and Place	Lecturer	Subject of Discourse
1842. Manchester	Charles Vignoles, F.R.S......	The Principles and Construction of Atmospheric Railways.
	Sir M. I. Brunel	The Thames Tunnel.
	R. I. Murchison..................	The Geology of Russia.
1843. Cork	Prof. Owen, M.D., F.R.S.......	The Dinornis of New Zealand.
	Prof. E. Forbes, F.R.S..........	The Distribution of Animal Life in the Ægean Sea.
	Dr. Robinson......................	The Earl of Rosse's Telescope.
1844. York	Charles Lyell, F.R.S.	Geology of North America.
	Dr. Falconer, F.R.S.............	The Gigantic Tortoise of the Siwalik Hills in India.
1845. Cambridge	G.B.Airy,F.R.S.,Astron.Royal	Progress of Terrestrial Magnetism.
	R. I. Murchison, F.R.S.	Geology of Russia.
1846. Southampton.	Prof. Owen, M.D., F.R.S. ...	Fossil Mammalia of the British Isles.
	Charles Lyell, F.R.S.	Valley and Delta of the Mississippi.
	W. R. Grove, F.R.S.............	Properties of the Explosive substance discovered by Dr. Schönbein; also some Researches of his own on the Decomposition of Water by Heat.
1847. Oxford......	Rev. Prof. B. Powell, F.R.S.	Shooting Stars.
	Prof. M. Faraday, F.R.S.......	Magnetic and Diamagnetic Phenomena.
	Hugh E. Strickland, F.G.S....	The Dodo (*Didus ineptus*).

Date and Place	Lecturer	Subject of Discourse
1848. Swansea ...	John Percy, M.D., F.R.S.......	Metallurgical Operations of Swansea and its neighbourhood.
	W. Carpenter, M.D., F.R.S....	Recent Microscopical Discoveries.
1849. Birmingham	Dr. Faraday, F.R.S.	Mr. Gassiot's Battery.
	Rev. Prof. Willis, M.A., F.R.S.	Transit of different Weights with varying velocities on Railways.
1850. Edinburgh	Prof. J. H. Bennett, M.D., F.R.S.E.	Passage of the Blood through the minute vessels of Animals in connexion with Nutrition.
	Dr. Mantell, F.R.S.	Extinct Birds of New Zealand.
1851. Ipswich ...	Prof. R. Owen, M.D., F.R.S.	Distinction between Plants and Animals, and their changes of Form.
	G.B. Airy, F.R.S., Astron. Royal	Total Solar Eclipse of July 28, 1851.
1852. Belfast......	Prof. G. G. Stokes, D.C.L., F.R.S.	Recent discoveries in the properties of Light.
	Colonel Portlock, R.E., F.R.S.	Recent discovery of Rock-salt at Carrickfergus, and geological and practical considerations connected with it.
1853. Hull	Prof. J. Phillips, LL.D., F.R.S., F.G.S.	Some peculiar Phenomena in the Geology and Physical Geography of Yorkshire.
	Robert Hunt, F.R.S.............	The present state of Photography.
1854. Liverpool...	Prof. R. Owen, M.D., F.R.S.	Anthropomorphous Apes.
	Col. E. Sabine, V.P.R.S.	Progress of researches in Terrestrial Magnetism.
1855. Glasgow ...	Dr. W. B. Carpenter, F.R.S.	Characters of Species.
	Lieut.-Col. H. Rawlinson ...	Assyrian and Babylonian Antiquities and Ethnology.
1856. Cheltenham	Col. Sir H. Rawlinson	Recent Discoveries in Assyria and Babylonia, with the results of Cuneiform research up to the present time.
	W. R. Grove, F.R.S............	Correlation of Physical Forces.
1857. Dublin......	Prof. W. Thomson, F.R.S. ...	The Atlantic Telegraph.
	Rev. Dr. Livingstone, D.C.L.	Recent Discoveries in Africa.
1858. Leeds	Prof. J. Phillips, LL.D., F.R.S.	The Ironstones of Yorkshire.
	Prof. R. Owen, M.D., F.R.S.	The Fossil Mammalia of Australia.
1859. Aberdeen...	Sir R. I. Murchison, D.C.L....	Geology of the Northern Highlands.
	Rev. Dr. Robinson, F.R.S. ...	Electrical Discharges in highly rarefied Media.
1860. Oxford......	Rev. Prof. Walker, F.R.S. ...	Physical Constitution of the Sun.
	Captain Sherard Osborn, R.N.	Arctic Discovery.
1861. Manchester	Prof. W. A. Miller, M.A., F.R.S.	Spectrum Analysis.
	G.B. Airy, F.R.S., Astron. Royal	The late Eclipse of the Sun.
1862. Cambridge	Prof. Tyndall, LL.D., F.R.S.	The Forms and Action of Water.
	Prof. Odling, F.R.S............	Organic Chemistry.
1863. Newcastle	Prof. Williamson, F.R.S.......	The Chemistry of the Galvanic Battery considered in relation to Dynamics.
	James Glaisher, F.R.S.........	The Balloon Ascents made for the British Association.
1864. Bath.........	Prof. Roscoe, F.R.S............	The Chemical Action of Light.
	Dr. Livingstone, F.R.S.	Recent Travels in Africa.
1865. Birmingham	J. Beete Jukes, F.R.S..........	Probabilities as to the position and extent of the Coal-measures beneath the red rocks of the Midland Counties.
1866. Nottingham	William Huggins, F.R.S. ...	The results of Spectrum Analysis applied to Heavenly Bodies.
	Dr. J. D. Hooker, F.R.S.......	Insular Floras.

Date and Place	Lecturer	Subject of Discourse
1867. Dundee......	Archibald Geikie, F.R.S.......	The Geological Origin of the present Scenery of Scotland.
	Alexander Herschel, F.R.A.S.	The present state of knowledge regarding Meteors and Meteorites.
1868. Norwich ...	J. Fergusson, F.R.S............	Archæology of the early Buddhist Monuments.
	Dr. W. Odling, F.R.S.	Reverse Chemical Actions.
1869. Exeter	Prof. J. Phillips, LL.D., F.R.S.	Vesuvius.
	J. Norman Lockyer, F.R.S....	The Physical Constitution of the Stars and Nebulæ.
1870. Liverpool...	Prof. J. Tyndall, LL.D., F.R.S.	The Scientific Use of the Imagination.
	Prof. W. J. Macquorn Rankine, LL.D., F.R.S.	Stream-lines and Waves, in connection with Naval Architecture.
1871. Edinburgh	F. A. Abel, F.R.S...............	Some recent investigations and applications of Explosive Agents.
	E. B. Tylor, F.R.S.	The Relation of Primitive to Modern Civilization.
1872. Brighton ...	Prof. P. Martin Duncan, M.B., F.R.S.	Insect Metamorphosis.
	Prof. W. K. Clifford	The Aims and Instruments of Scientific Thought.
1873. Bradford ...	Prof. W. C. Williamson, F.R.S.	Coal and Coal Plants.
	Prof. Clerk Maxwell, F.R.S.	Molecules.
1874. Belfast	Sir John Lubbock, Bart., M.P., F.R.S.	Common Wild Flowers considered in relation to Insects.
	Prof. Huxley, F.R.S.	The Hypothesis that Animals are Automata, and its History.
1875. Bristol	W. Spottiswoode, LL.D., F.R.S.	The Colours of Polarized Light.
	F. J. Bramwell, F.R.S..........	Railway Safety Appliances.
1876. Glasgow ...	Prof. Tait, F.R.S.E.	Force.
	Sir Wyville Thomson, F.R.S.	The *Challenger* Expedition.
1877. Plymouth...	W. Warington Smyth, M.A., F.R.S.	The Physical Phenomena connected with the Mines of Cornwall and Devon.
	Prof. Odling, F.R.S............	The new Element, Gallium.
1878. Dublin	G. J. Romanes, F.L.S.	Animal Intelligence.
	Prof. Dewar, F.R.S.	Dissociation, or Modern Ideas of Chemical Action.
1879. Sheffield ...	W. Crookes, F.R.S.	Radiant Matter.
	Prof. E. Ray Lankester, F.R.S.	Degeneration.
1880. Swansea ...	Prof. W. Boyd Dawkins, F.R.S.	Primeval Man.
	Francis Galton, F.R.S..........	Mental Imagery.
1881. York.........	Prof. Huxley, Sec. R.S.	The Rise and Progress of Palæontology.
	W. Spottiswoode, Pres. R.S.	The Electric Discharge, its Forms and its Functions.
1882. Southampton.	Prof. Sir Wm. Thomson, F.R.S.	Tides.
	Prof. H. N. Moseley, F.R.S.	Pelagic Life.
1883. Southport	Prof. R. S. Ball, F.R.S.	Recent Researches on the Distance of the Sun.
	Prof. J. G. McKendrick, F.R.S.E.	Galvani and Animal Electricity.
1884. Montreal...	Prof. O. J. Lodge, D.Sc.	Dust.
	Rev. W. H. Dallinger, F.R.S.	The Modern Microscope in Researches on the Least and Lowest Forms of Life.
1885. Aberdeen...	Prof. W. G. Adams, F.R.S. ...	The Electric Light and Atmospheric Absorption.
	John Murray, F.R.S.E..........	The Great Ocean Basins.

LECTURES TO THE OPERATIVE CLASSES.

Date and Place	Lecturer	Subject of Discourse
1867. Dundee......	Prof. J. Tyndall, LL.D., F.R.S.	Matter and Force.
1868. Norwich ...	Prof. Huxley, LL.D., F.R.S.	A Piece of Chalk.
1869. Exeter	Prof. Miller, M.D., F.R.S. ...	Experimental illustrations of the modes of detecting the Composition of the Sun and other Heavenly Bodies by the Spectrum.
1870. Liverpool...	Sir John Lubbock, Bart., M.P., F.R.S.	Savages.
1872. Brighton ...	W. Spottiswoode, LL.D., F.R.S.	Sunshine, Sea, and Sky.
1873. Bradford ...	C. W. Siemens, D.C.L., F.R.S.	Fuel.
1874. Belfast	Prof. Odling, F.R.S............	The Discovery of Oxygen.
1875. Bristol	Dr. W. B. Carpenter, F.R.S.	A Piece of Limestone.
1876. Glasgow ...	Commander Cameron, C.B., R.N.	A Journey through Africa.
1877. Plymouth...	W. H. Preece.....................	Telegraphy and the Telephone.
1879. Sheffield ...	W. E. Ayrton	Electricity as a Motive Power.
1880. Swansea ...	H. Seebohm, F.Z.S.	The North-East Passage.
1881. York	Prof. Osborne Reynolds, F.R.S.	Raindrops, Hailstones, and Snowflakes.
1882. Southampton.	John Evans, D.C.L. Treas. R.S.	Unwritten History, and how to read it.
1883. Southport	Sir F. J. Bramwell, F.R.S. ...	Talking by Electricity—Telephones.
1884. Montreal ...	Prof. R. S. Ball, F.R.S.........	Comets.
1885. Aberdeen...	H. B. Dixon, M.A.	The Nature of Explosions.

OFFICERS OF SECTIONAL COMMITTEES PRESENT AT THE ABERDEEN MEETING.

SECTION A.—MATHEMATICAL AND PHYSICAL SCIENCE.

President.—Professor G. Chrystal, M.A., F.R.S.E.

Vice-Presidents.—Professor C. Niven, F.R.S.; Lord Rayleigh, F.R.S.; Professor A. Schuster, F.R.S.; Professor G. G. Stokes, Sec.R.S.; Professor Sir W. Thomson, F.R.S.

Secretaries—R. E. Baynes, M.A.; R. T. Glazebrook, F.R.S.; Professor W. M. Hicks, F.R.S. (*Recorder*); Professor W. Ingram, M.A.

SECTION B.—CHEMICAL SCIENCE.

President.—Professor H. E. Armstrong, Ph.D., F.R.S., Sec.C.S.

Vice-Presidents.—Professor Brazier, F.C.S.; Professor A. Crum Brown, F.R.S.; Professor Hartley, F.R.S.; Professor H. McLeod, F.R.S.; Professor W. A. Tilden, F.R.S.

Secretaries.—Professor P. Phillips Bedson, D.Sc. (*Recorder*); H. B. Dixon, M.A.; H. Forster Morley, D.Sc.; W. J. Simpson, M.D.

SECTION C.—GEOLOGY.

President.—Professor J. W. Judd, F.R.S., Sec.G.S.

Vice-Presidents.—John Evans, Treas.R.S.; Rev. George Gordon, LL.D.; T. F. Jamieson, LL.D.; Rev. J. M. Joass, LL.D.; Professor O. C. Marsh, M.A.; Professor W. C. Williamson, F.R.S.

Secretaries.—C. E. De Rance, F.G.S.; J. Horne, F.R.S.E.; J. J. H. Teall, F.G.S.; W. Topley, F.G.S. (*Recorder*).

SECTION D.—BIOLOGY.

President.—Professor W. C. McIntosh, M.D., LL.D., F.R.S. L. and E., F.L.S.

Vice-Presidents.—Professor C. C. Babington, F.R.S.; Professor I. Bayley Balfour, F.R.S.; Professor Cleland, F.R.S.; Sir John Lubbock, Bart., F.R.S.; Professor J. S. Burdon Sanderson, F.R.S.; Professor W. Stirling, F.R.S.E.; Professor Trail, F.L.S.

Secretaries.—W. Heape; J. McGregor-Robertson, M.B.; J. Duncan Matthews, F.R.S.E.; Howard Saunders, F.L.S. (*Recorder*); H. Marshall Ward, M.A.

SECTION E.—GEOGRAPHY.

President.—General J. T. Walker, C.B., R.E., LL.D., F.R.S.

Vice-Presidents.—Professor James Donaldson, F.R.S.E.; Admiral Sir E. Ommanney, C.B., F.R.S.; Lieut.-Colonel R. L. Playfair; Dr. John Rae, F.R.S.

Secretaries.—J. S. Keltie; J. S. O'Halloran, F.R.G.S.; E. G. Ravenstein, F.R.G.S. (*Recorder*); Rev. G. A. Smith, M.A.

SECTION F.—ECONOMIC SCIENCE AND STATISTICS.

President.—Professor Henry Sidgwick, LL.D., Litt.D.

Vice-Presidents.—Professor Adamson, LL.D.; Dr. Alexander Bain; Major P. G. Craigie; Sir Richard Temple, Bart., G.C.S.I.

Secretaries.—Rev. W. Cunningham, B.D.; Professor H. S. Foxwell, M.A. (*Recorder*); C. McCombie; J. F. Moss.

SECTION G.—MECHANICAL SCIENCE.

President.—Benjamin Baker, M.Inst.C.E.

Vice-Presidents.—W. H. Barlow, F.R.S.; Sir James N. Douglass; Professor James Thomson, F.R.S.; Professor W. C. Unwin.

Secretaries.—A. T. Atchison, M.A.; F. G. Ogilvie, M.A., B.Sc.; E. Rigg, M.A. (*Recorder*); J. N. Shoolbred, B.A.

SECTION H.—ANTHROPOLOGY.

President.—Francis Galton, M.A., F.R.S., President of the Anthropological Institute.

Vice-Presidents.—Dr. Alexander Bain; Professor D. J. Cunningham, M.D.; Professor Flower, F.R.S.; W. Pengelly, F.R.S.; Professor Struthers, M.D.; Professor W. Turner, F.R.S.

Secretaries.—G. W. Bloxam, F.L.S. (*Recorder*); J. G. Garson, M.D.; Walter Hurst, B.Sc.; A. McGregor, M.D.

THE GENERAL TREASURER'S ACCOUNT (not including receipts at the Aberdeen Meeting).

RECEIPTS.

1884–85.	RECEIPTS.	£	s.	d.
	By Balance of account presented at Montreal Meeting	1275	19	9
	Received for Life Compositions to date	210	0	0
	" " Annual Subscriptions to date	334	0	0
	" " Transfers	34	0	0
	Dividends on Stock	247	0	8
	Interest on Exchequer Bills	48	15	3
	Sale of Publications	142	12	4
1884.				
Oct. 29.	Received for Rent from Mathematical Society, year ending September 29, 1884	12	15	0
Sept. 15.	By amount of grant for 'Coagulation of Blood'	50	0	0
1885.				
May 29.	Unexpended balance of grant for the 'Exploration of Mount Kilima-njaro'	25	0	0
	By Transfer of Balance of Account rendered by Financial Officer at Montreal Meeting, less £3 17s.	1537	9	9
		£3917	12	9

PAYMENTS.

1884–85.	PAYMENTS.	£	s.	d.
	By part paid Expenses of Montreal Meeting, also sundry Printing, Binding, Advertising, and Incidental Expenses	289	1	7
1885.				
Aug. 14.	By Messrs. Spottiswoode & Co.'s account for printing—year 1884–85	1000	19	9
	Salaries (1 year, 1884–85)	505	0	0
	Rent of Office at Albemarle Street	117	0	0
	Grants:—			

Date		Grant	£
1884.			
Nov.	1.	Zoological Literature Record	100
"	1.	Vapour Pressures, &c., of Salt Solutions	25
"	1.	Physical Constants of Solutions	20
"	1.	Recent Polyzoa	10
"	12.	Naples Zoological Station	100
"	15.	Exploration of Mount Kilima-njaro	25
" / March	15. / 26.	Fossil Plants of British Tertiary and Secondary Beds	50
Dec.	10.	Calculating Tables in Theory of Numbers	100
1885.			
Jan.	14.	Exploration of New Guinea	200
March	5.	Exploration of Mount Roraima	100
April	13.	Meteorological Observations on Ben Nevis	50
"	13.	Volcanic Phenomena of Vesuvius	25
"	24.	Biological Stations on Coasts of United Kingdom	150
June	1.	Meteoric Dust	70
"	1.	Marine Biological Station at Granton	100
"	6.	Fossil Phyllopoda of Palæozoic Rocks	25
July	10.	Migration of Birds	30
"	10.	Synoptic Chart of Indian Ocean	50
" / Aug.	20. / 21.	Circulation of Underground Waters	10
July	28.	Geological Record	50
"	30.	Reduction of Tidal Observations	10
Aug.	10.	Earthquake Phenomena of Japan	70
"	21.	Raygill Fissure	15

				£	s.	d.
(Grants total)				1385	0	0
Balance at Bank of England, Western Branch	£436	0	0			
In hands of Assistant to General Treasurer	184	11	5			
				620	11	5
				£3917	12	9

ALEX. W. WILLIAMSON.

Table showing the Attendance and Receipt

Date of Meeting	Where held	Presidents	Old Life Members	New Life Members
1831, Sept. 27 ...	York	The Earl Fitzwilliam, D.C.L.	...	...
1832, June 19 ...	Oxford	The Rev. W. Buckland, F.R.S.	...	...
1833, June 25 ...	Cambridge	The Rev. A. Sedgwick, F.R.S.	...	...
1834, Sept. 8 ...	Edinburgh	Sir T. M. Brisbane, D.C.L.......	...	...
1835, Aug. 10 ...	Dublin	The Rev. Provost Lloyd, LL.D.	...	...
1836, Aug. 22 ...	Bristol	The Marquis of Lansdowne ...	...	...
1837, Sept. 11 ...	Liverpool	The Earl of Burlington, F.R.S.	...	...
1838, Aug. 10 ...	Newcastle-on-Tyne	The Duke of Northumberland	...	...
1839, Aug. 26 ...	Birmingham.........	The Rev. W. Vernon Harcourt	...	...
1840, Sept. 17 ...	Glasgow	The Marquis of Breadalbane...	...	...
1841, July 20 ...	Plymouth	The Rev. W. Whewell, F.R.S.	169	65
1842, June 23 ...	Manchester	The Lord Francis Egerton......	303	169
1843, Aug. 17 ...	Cork	The Earl of Rosse, F.R.S.	109	28
1844, Sept. 26 ...	York	The Rev. G. Peacock, D.D. ...	226	150
1845, June 19 ...	Cambridge	Sir John F. W. Herschel, Bart.	313	36
1846, Sept. 10 ...	Southampton	Sir Roderick I. Murchison, Bart.	241	10
1847, June 23 ...	Oxford	Sir Robert H. Inglis, Bart.......	314	18
1848, Aug. 9 ...	Swansea	The Marquis of Northampton	149	3
1849, Sept. 12 ...	Birmingham.........	The Rev. T. R. Robinson, D.D.	227	12
1850, July 21 ...	Edinburgh	Sir David Brewster, K.H.	235	9
1851, July 2 ...	Ipswich	G. B. Airy, Astronomer Royal	172	8
1852, Sept. 1 ...	Belfast	Lieut.-General Sabine, F.R.S.	164	10
1853, Sept. 3 ...	Hull	William Hopkins, F.R.S.	141	13
1854, Sept. 20 ...	Liverpool	The Earl of Harrowby, F.R.S.	238	23
1855, Sept. 12 ...	Glasgow	The Duke of Argyll, F.R.S. ...	194	33
1856, Aug. 6 ...	Cheltenham	Prof. C. G. B. Daubeny, M.D.	182	14
1857, Aug. 26 ...	Dublin	The Rev. Humphrey Lloyd, D.D.	236	15
1858, Sept. 22 ...	Leeds..................	Richard Owen, M.D., D.C.L....	222	42
1859, Sept. 14 ...	Aberdeen	H.R.H. the Prince Consort ...	184	27
1860, June 27 ...	Oxford	The Lord Wrottesley, M.A. ...	286	21
1861, Sept. 4 ...	Manchester	William Fairbairn, LL.D., F.R.S.	321	113
1862, Oct. 1 ...	Cambridge	The Rev. Professor Willis, M.A.	239	15
1863, Aug. 26 ...	Newcastle-on-Tyne	Sir William G. Armstrong, C.B.	203	36
1864, Sept. 13 ...	Bath	Sir Charles Lyell, Bart., M.A.	287	40
1865, Sept. 6 ...	Birmingham.........	Prof. J. Phillips, M.A., LL.D.	292	44
1866, Aug. 22 ...	Nottingham	William R. Grove, Q.C., F.R.S.	207	31
1867, Sept. 4 ...	Dundee	The Duke of Buccleuch, K.C.B.	167	25
1868, Aug. 19 ...	Norwich	Dr. Joseph D. Hooker, F.R.S.	196	18
1869, Aug. 18 ...	Exeter	Prof. G. G. Stokes, D.C.L.	204	21
1870, Sept. 14 ...	Liverpool	Prof. T. H. Huxley, LL.D.......	314	39
1871, Aug. 2 ...	Edinburgh	Prof. Sir W. Thomson, LL.D.	246	28
1872, Aug. 14 ...	Brighton	Dr. W. B. Carpenter, F.R.S. ...	245	36
1873, Sept. 17 ...	Bradford	Prof. A. W. Williamson, F.R.S.	212	27
1874, Aug. 19 ...	Belfast	Prof. J. Tyndall, LL.D., F.R.S.	162	13
1875, Aug. 25 ...	Bristol	Sir John Hawkshaw, C.E., F.R.S.	239	36
1876, Sept. 6 ...	Glasgow	Prof. T. Andrews, M.D., F.R.S.	221	35
1877, Aug. 15 ...	Plymouth	Prof. A. Thomson, M.D., F.R.S.	173	19
1878, Aug. 14 ...	Dublin	W. Spottiswoode, M.A., F.R.S.	201	18
1879, Aug. 20 ...	Sheffield	Prof. G. J. Allman, M.D., F.R.S.	184	16
1880, Aug. 25 ...	Swansea	A. C. Ramsay, LL.D., F.R.S....	144	11
1881, Aug. 31 ...	York	Sir John Lubbock, Bart., F.R.S.	272	28
1882, Aug. 23 ...	Southampton	Dr. C. W. Siemens, F.R.S.......	178	17
1883, Sept. 19 ...	Southport	Prof. A. Cayley, D.C.L., F.R.S.	203	60
1884, Aug. 27 ...	Montreal	Prof. Lord Rayleigh, F.R.S. ...	235	20
1885, Sept. 9 ...	Aberdeen	Sir Lyon Playfair, K.C.B., F.R.S.	225	18

Annual Meetings of the Association.

Attended by						Amount received during the Meeting	Sums paid on Account of Grants for Scientific Purposes	Year
Old Annual Members	New Annual Members	Associates	Ladies	Foreigners	Total			
...	...	...	...	...	353	....	....	1831
...	...	...	...	...	...	....	....	1832
...	...	...	...	...	900	....	....	1833
...	...	...	...	...	1298	....	£20 0 0	1834
...	...	...	...	...	...	....	167 0 0	1835
...	...	...	...	...	1350	....	435 0 0	1836
...	...	...	...	...	1840	....	922 12 6	1837
...	...	...	1100*	...	2400	....	932 2 2	1838
...	...	...	...	34	1438	....	1595 11 0	1839
...	...	...	...	40	1353	....	1546 16 4	1840
46	317	...	60*	...	891	....	1235 10 11	1841
75	376	33†	331*	28	1315	....	1449 17 8	1842
71	185	...	160	...	...	....	1565 10 2	1843
45	190	9†	260	...	...	....	981 12 8	1844
94	22	407	172	35	1079	....	831 9 9	1845
65	39	270	196	36	857	....	685 16 0	1846
197	40	495	203	53	1320	....	208 5 4	1847
54	25	376	197	15	819	£707 0 0	275 1 8	1848
93	33	447	237	22	1071	963 0 0	159 19 6	1849
128	42	510	273	44	1241	1085 0 0	345 18 0	1850
61	47	244	141	37	710	620 0 0	391 9 7	1851
63	60	510	292	9	1108	1085 0 0	304 6 7	1852
56	57	367	236	6	876	903 0 0	205 0 0	1853
121	121	765	524	10	1802	1882 0 0	380 19 7	1854
142	101	1094	543	26	2133	2311 0 0	480 16 4	1855
104	48	412	346	9	1115	1098 0 0	734 13 9	1856
156	120	900	569	26	2022	2015 0 0	507 15 4	1857
111	91	710	509	13	1698	1931 0 0	618 18 2	1858
125	179	1206	821	22	2564	2782 0 0	684 11 1	1859
177	59	636	463	47	1689	1604 0 0	766 19 6	1860
184	125	1589	791	15	3138	3944 0 0	1111 5 10	1861
150	57	433	242	25	1161	1089 0 0	1293 16 6	1862
154	209	1704	1004	25	3335	3640 0 0	1608 3 10	1863
182	103	1119	1058	13	2802	2965 0 0	1289 15 8	1864
215	149	766	508	23	1997	2227 0 0	1591 7 10	1865
218	105	960	771	11	2303	2469 0 0	1750 13 4	1866
193	118	1163	771	7	2444	2613 0 0	1739 4 0	1867
226	117	720	682	45‡	2004	2042 0 0	1940 0 0	1868
229	107	678	600	17	1856	1931 0 0	1622 0 0	1869
303	195	1103	910	14	2878	3096 0 0	1572 0 0	1870
311	127	976	754	21	2463	2575 0 0	1472 2 6	1871
280	80	937	912	43	2533	2649 0 0	1285 0 0	1872
237	99	796	601	11	1983	2120 0 0	1685 0 0	1873
232	85	817	630	12	1951	1979 0 0	1151 16 0	1874
307	93	884	672	17	2248	2397 0 0	960 0 0	1875
331	185	1265	712	25	2774	3023 0 0	1092 4 2	1876
238	59	446	283	11	1229	1268 0 0	1128 9 7	1877
290	93	1285	674	17	2578	2615 0 0	725 16 6	1878
239	74	529	349	13	1404	1425 0 0	1080 11 11	1879
171	41	389	147	12	915	899 0 0	731 7 7	1880
313	176	1230	514	24	2557	2689 0 0	476 3 1	1881
253	79	516	189	21	1253	1286 0 0	1126 1 11	1882
330	323	952	841	5	2714	3369 0 0	1083 3 3	1883
317	219	826	74	26 & 60 H.§	1777	1538 0 0	1173 4 0	1884
332	122	1053	447	6	2203	2256 0 0	1385 0 0	1885

...dies were not admitted by purchased Tickets until 1843. † Tickets of Admission to Sections only.
...cluding Ladies. § Fellows of the American Association were admitted as Honorary Members for this Meeting.

OFFICERS AND COUNCIL, 1885-86.

PRESIDENT.

The Right Hon. SIR LYON PLAYFAIR, K.C.B., M.P., Ph.D., LL.D., F.R.S. L. & E., F.C.S.

VICE-PRESIDENTS.

His Grace the Duke of Richmond and Gordon, K.G., D.C.L., Chancellor of the University of Aberdeen.
The Right Hon. the Earl of Aberdeen, LL.D., Lord-Lieutenant of Aberdeenshire.
The Right Hon. the Earl of Crawford and Balcarres, M.A., LL.D., F.R.S., F.R.A.S.
James Matthews, Esq., Lord Provost of the City of Aberdeen.
Professor Sir William Thomson, M.A., LL.D., F.R.S. L. & E., F.R.A.S.
Alexander Bain, Esq., M.A., LL.D., Rector of the University of Aberdeen.
Professor W. H. Flower, LL.D., F.R.S., F.L.S., F.G.S., Pres. Z.S., Director of the Natural History Museum, London.
Professor John Struthers, M.D., LL.D.

PRESIDENT ELECT.

Sir William Dawson, C.M.G., M.A., LL.D., F.R.S., F.G.S., Principal of McGill College, Montreal, Canada.

VICE-PRESIDENTS ELECT.

The Right Hon. the Earl of Bradford, Lord-Lieutenant of Shropshire.
The Right Hon. Lord Leigh, D.C.L., Lord-Lieutenant of Warwickshire.
The Right Hon. Lord Norton, K.C.M.G.
The Right Hon. Lord Wrottesley, Lord-Lieutenant of Staffordshire.
The Right Rev. the Lord Bishop of Worcester, D.D.
Thomas Martineau, Esq., Mayor of Birmingham.
Professor G. G. Stokes, D.C.L., LL.D., Pres. R.S.
Professor W. A. Tilden, D.Sc., F.R.S., F.C.S.
Rev. A. R. Vardy, M.A.
Rev. A. W. Watson, D.Sc., F.R.S.

LOCAL SECRETARIES FOR THE MEETING AT BIRMINGHAM.

J. Barham Carslake, Esq. | Rev. H. W. Crosskey, LL.D., F.G.S. | Charles J. Hart, Esq.

LOCAL TREASURER FOR THE MEETING AT BIRMINGHAM.

J. D. Goodman, Esq.

ORDINARY MEMBERS OF THE COUNCIL.

Abney, Capt. W. de W., F.R.S.
Ball, Professor R. S., F.R.S.
Bateman, J. F. La Trobe, Esq., F.R.S.
Blanford, W. T., Esq., F.R.S.
Bramwell, Sir F. J., F.R.S.
Crookes, W., Esq., F.R.S.
Dawkins, Professor W. Boyd, F.R.S.
De La Rue, Dr. Warren, F.R.S.
Dewar, Professor J., F.R.S.
Flower, Professor W. H., F.R.S.
Gladstone, Dr. J. H., F.R.S.
Glaisher, J. W. L., Esq., F.R.S.
Godwin-Austen, Lieut.-Col. H. H., F.R.S.
Hawkshaw, J. Clarke, Esq., F.G.S.
Henrici, Professor O., F.R.S.
Hughes, Professor T. McK., F.G.S.
Martin, J. B., Esq., F.S.S.
M'Leod, Professor H., F.R.S.
Moseley, Professor H. N., F.R.S.
Ommanney, Admiral Sir E., C.B., F.R.S.
Pengelly, W., Esq., F.R.S.
Perkin, Dr. W. H., F.R.S.
Sorby, Dr. H. C., F.R.S.
Temple, Sir R., Bart., G.C.S.I.
Thiselton-Dyer, W. T., Esq., C.M.G., F.R.S.

GENERAL SECRETARIES.

Capt. Douglas Galton, C.B., D.C.L., LL.D., F.R.S., F.G.S., 12 Chester Street, London, S.W.
A. G. Vernon Harcourt, Esq., M.A., LL.D., F.R.S., F.C.S., Cowley Grange, Oxford.

SECRETARY.

Arthur T. Atchison, Esq., M.A., 22 Albemarle Street, London, W.

GENERAL TREASURER.

Professor A. W. Williamson, Ph.D., LL.D., F.R.S., F.C.S., University College, London, W.C.

EX-OFFICIO MEMBERS OF THE COUNCIL.

The Trustees, the President and President Elect, the Presidents of former years, the Vice-Presidents and Vice-Presidents Elect, the General and Assistant General Secretaries for the present and former years, the Secretary, the General Treasurers for the present and former years, and the Local Treasurer and Secretaries for the ensuing Meeting.

TRUSTEES (PERMANENT).

Sir John Lubbock, Bart., M.P., D.C.L., LL.D., F.R.S., Pres. L.S.
The Right Hon. Lord Rayleigh, M.A., D.C.L., LL.D., Sec. R.S., F.R.A.S.
The Right Hon. Sir Lyon Playfair, K.C.B., M.P., Ph.D., LL.D., F.R.S.

PRESIDENTS OF FORMER YEARS.

The Duke of Devonshire, K.G.
Sir G. B. Airy, K.C.B., F.R.S.
The Duke of Argyll, K.G., K.T.
Sir Richard Owen, K.C.B., F.R.S.
Sir W. G. Armstrong, C.B., LL.D.
Sir William R. Grove, F.R.S.
Sir Joseph D. Hooker, K.C.S.I.
Prof. Stokes, D.C.L., Pres. R.S.
Prof. Huxley, LL.D., F.R.S.
Prof. Sir Wm. Thomson, LL.D.
Prof. Williamson, Ph.D., F.R.S.
Prof. Tyndall, D.C.L., F.R.S.
Sir John Hawkshaw, F.R.S.
Prof. Allman, M.D., F.R.S.
Sir A. C. Ramsay, LL.D., F.R.S.
Sir John Lubbock, Bart., F.R.S.
Prof. Cayley, LL.D., F.R.S.
Lord Rayleigh, D.C.L., Sec. R.S.

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Dr. Michael Foster, Sec. R.S.
George Griffith, Esq., M.A., F.C.S.
P. L. Sclater, Esq., Ph.D., F.R.S.
Prof. Bonney, D.Sc., F.R.S.

AUDITORS.

John Evans, Esq., D.C.L., F.R.S. | W. Huggins, Esq., D.C.L., F.R.S. | W. H. Preece, Esq., F.R.S.

REPORT OF THE COUNCIL.

Report of the Council for the year 1884–85, *presented to the General Committee at Aberdeen, on Wednesday, September* 9, 1885.

The Council have received reports during the past year from the General Treasurer, and his accounts for the year will be laid before the General Committee this day.

Since the Meeting at Montreal, the following have been elected Corresponding Members of the Association:—

Bowditch, Prof. H. P.
Brush, Prof. G. J.
Gibbs, Prof. J. Willard.
Gibbs, Prof. Wolcott.
Greely, Lieut. A. W.
Jackson, Prof. C. Loring.
Kikuchi, Prof. Dairoku.
Michelson, A. A.
Newcomb, Prof. Simon.
Powell, Major J. W.
Ray, Captain P. H.
Thurston, Prof. R. H.

The Council have nominated Professor Struthers, M.D., LL.D., to be a Vice-President at the Meeting at Aberdeen.

Soon after the commencement of the present year, Professor Bonney, the Secretary, informed the Council that a considerable increase in the endowment of his Professorship at University College would demand that in future a larger share of his time should be devoted to teaching. As unfortunately the state of his health for some months past had pointed to the need of diminishing rather than increasing his work, he regretted that he would be unable to offer himself for re-election at the present Meeting. The Council received this announcement with very great regret. Professor Bonney not only brought to the office of Secretary a leading scientific position, but also combined with this advantage great energy, zeal, and discretion. It was largely due to his powers of organisation and tact that the exceptional and grave difficulties which attended the holding of last year's Meeting at Montreal were surmounted, and it was brought to a successful issue. The Council have nominated Mr. A. T. Atchison, M.A., who for some years past has rendered most efficient assistance as one of the Secretaries of Section G, to the office of Secretary, vacated by Professor Bonney.

During the present year the Council have considered the stipend paid to Mr. Stewardson, the Clerk of the Association, and the amount assigned to the General Treasurer to enable him to obtain such assistance as may be requisite. Mr. Stewardson was engaged in the year 1873 at a salary of 120*l.*, which was subsequently augmented to 130*l.* The Council now recommend that for the present year it be raised to 135*l.*, and be subsequently increased (subject to the usual conditions) by a sum of 5*l.* at the end of each three years till a maximum of 160*l.* be reached; also that the yearly sum assigned to the General Treasurer be increased from 50*l.* to 60*l.*

On meeting again in Great Britain, the Council venture to express to the General Committee their belief that the anticipations of a successful meeting, expressed in the Report presented at Montreal, have been fully justified by the results, and once more give utterance to the gratitude, which must be felt by all who visited Canada, for the liberal hospitality and cordial reception which welcomed them there. It will be long before this visit is forgotten, or the stimulus, which its exceptional circumstances gave to the energy and life of the Association, ceases to be felt. Towards the close of that Meeting the happy idea occurred to several members of the Association that it would be an appropriate memorial of the visit of the British Association to found a Medal at McGill University, to be given annually for proficiency in Applied Science. The idea, once started, was warmly espoused, and a subscription list was opened, with Lord Rayleigh, the President, as Treasurer, and Messrs. W. Topley and H. T. Wood as Secretaries. The result has been that a sum of about 500*l.* will be transmitted to the authorities of the McGill University for investment. This will enable them to offer, as an annual prize, a Gold Medal and a sum of money. The first award has already been made. The Council, acting under the powers conferred upon them by the General Committee on Nov. 11, 1884, have instructed Mr. Wyon to prepare, at the cost of the Association, a suitable die for the Medal.

The Council, in virtue of the powers conferred upon them by the General Committee at Montreal, in regard to the report concerning Corresponding Societies, have formed the Corresponding Societies' Committee. The Report of the Committee will be presented, and a conference of Delegates, appointed under the new rules, will be held during the present meeting.

The following resolutions were referred by the General Committee to the Council for consideration and action, if desirable:—

'That the Council of the Association be requested to communicate with the Government of the Dominion of Canada in order (1) to call the attention of the Government to the absence of trustworthy information concerning the tides of the Gulf of St. Lawrence and the adjoining Atlantic coast, and to the dangers which thence arise to the navigation; (2) To urge upon the Government the importance of obtaining accurate and systematic tidal observations, and of tabulating and reducing the results by the scientific methods elaborated by Committees of the Association; and (3) to suggest the immediate establishment of a sufficient series of observing stations on the coast of the Dominion.'

A memorial in accordance with the above resolution was adopted by the Council and forwarded to the Government of the Dominion of Canada. To this a reply was received from the Canadian Minister of Marine, expressing regret that the Dominion Government were unable at the present time to undertake a special survey of the tides and currents in the Gulf of St. Lawrence. The Council, however, are not without hope that the proposed observations may be regarded as deferred rather than as refused.

'That the Council memorialise the Canadian Government as to the urgent necessity of encouraging investigation and publication of reports with respect to the physical characters, languages, social, industrial, and artistic condition of the native tribes of the Dominion.'

A memorial in accordance with the above was also adopted by the Council and forwarded to the Government of the Dominion of Canada.

The receipt of this was acknowledged, and the Council were informed that it would be duly considered by the Dominion Government.

'That the attention of the Council be drawn to the advisability of communicating with the Admiralty for the purpose of urging on them the importance of the employment of the Harmonic Analysis in the Reduction of Admiralty Tidal Observations.'

The above recommendation was duly considered, but the Council, while fully conscious of the importance of the subject, deemed the time inopportune for pressing the matter on the attention of the Admiralty.

'That the Council be requested to examine the feasibility of instituting a scheme for promoting an International Scientific Congress, to meet at intervals in different countries, and to report thereon to the General Committee at the next meeting of the Association.'

This most important question has been very fully considered by the Council during the past year. The importance of such a Congress can hardly be doubted; at the same time there are many serious difficulties in devising a practical scheme, and many considerations to be taken into account, before it would be prudent to undertake so great a departure from the ordinary procedure of the Association, as would be involved by such schemes as have seemed most feasible. The following is a brief history of what has been done: At the conclusion of the Montreal Meeting a Committee of the Council (of which Mr. Vernon Harcourt, the General Secretary, was a member) took the opportunity of being present at the meeting of the American Association at Philadelphia to confer with some members of the Committee in America, from whom the latest and most definite proposal of an International Scientific Association has emanated. After returning to England, a letter was received by Mr. Vernon Harcourt from Dr. S. C. Minot, Secretary to the above Committee, which was laid before a Committee of the Council. As a result of their consideration of this letter, the Secretary entered into an informal correspondence with Dr. C. S. Minot. The intent of this correspondence was to bring about an exchange of views and a discussion of certain difficulties which presented themselves at first sight, and as it, in effect, contains the outline of a scheme, the Council (with Dr. Minot's permission) have resolved to place it, together with extracts from his letter to Mr. Vernon Harcourt, in the hands of the General Committee. Copies of it are accordingly distributed with this Report. The Council, in the next place, deemed it desirable to ascertain what support the proposal of a joint meeting of the British Association and of the International Scientific Association, in the suggested rudimentary form, would meet with from the more important scientific societies in London; for, without their favourable countenance and the permission to use the rooms of such as were conveniently situated, the project would necessarily be abortive. A circular was accordingly addressed to a number of the London scientific societies, with the result that out of 29 societies which sent answers, three expressed their inability, in consequence of formal difficulties, to reply at present; two were opposed to the scheme; five were favourable; and the rest were not hostile. It should, however, be remarked, that while a willingness to lend rooms was very generally shown, any approbation of the scheme was expressed in very guarded terms, and amounted, in the majority of cases, to little more than a non-expression of disapproval. In these circumstances the Council invite the General Committee to take the matter into

their consideration during the Aberdeen Meeting, and suggest that the second meeting of the General Committee would be the most convenient opportunity for a discussion.

One vacancy in the Council has been caused by the lamented death of Dr. Gwyn Jeffreys; another by the resignation of Prof. Prestwich; it follows, therefore, that in accordance with the rule, three other members will retire. The retiring members will be:—

Sir F. J. Evans. Prof. W. G. Adams.
The Right Hon. G. Sclater-Booth.

The Council recommend the re-election of the other ordinary Members of Council, with the addition of the gentlemen whose names are distinguished by an asterisk in the following list:—

Abney, Capt. W. de W., F.R.S.
Ball, Prof. R. S., F.R.S.
Bateman, J. F. La Trobe, Esq., F.R.S.
*Blanford, W. T., Esq., F.R.S.
Bramwell, Sir F. J., F.R.S.
*Crookes, W., Esq., F.R.S.
Dawkins, Prof. W. Boyd, F.R.S.
De La Rue, Dr. Warren, F.R.S.
Dewar, Prof. J., F.R.S.
Flower, Prof. W. H., F.R.S.
Gladstone, Dr. J. H., F.R.S.
Glaisher, J. W. L., Esq., F.R.S.
Godwin-Austen, Lieut.-Col. H. H., F.R.S.
Hawkshaw, J. Clarke, Esq., F.G.S.
Henrici, Prof. O., F.R.S.
Hughes, Prof. T. McK., F.G.S.
*Martin, J. B., Esq., F.S.S.
*M'Leod, Prof. H., F.R.S.
Moseley, Prof. H. N., F.R.S.
Ommanney, Admiral Sir E., C.B., F.R.S.
Pengelly, W., Esq., F.R.S.
Perkin, Dr. W. H., F.R.S.
Sorby, Dr. H. C., F.R.S.
Temple, Sir R., Bart., G.C.S.I.
*Thiselton-Dyer, W. T., Esq., C.M.G., F.R.S.

Recommendations adopted by the General Committee at the Aberdeen Meeting in September 1885.

[When Committees are appointed, the Member first named is regarded as the Secretary, except there is a specific nomination.]

Involving Grants of Money.

That Professor G. Carey Foster, Sir William Thomson, Professor Ayrton, Professor J. Perry, Professor W. G. Adams, Lord Rayleigh, Dr. O. J. Lodge, Dr. John Hopkinson, Dr. A. Muirhead, Mr. W. H. Preece, Mr. Herbert Taylor, Professor Everett, Professor Schuster, Dr. J. A. Fleming, Professor G. F. Fitzgerald, Mr. R. T. Glazebrook, Professor Chrystal, Mr. H. Tomlinson, Professor W. Garnett, Professor J. J. Thomson, and Mr. W. N. Shaw be reappointed a Committee for the purpose of constructing and issuing practical Standards for use in Electrical Measurements; that Mr. Glazebrook be the Secretary, and that the sum of 40*l.* be placed at their disposal for the purpose.

That Professor Balfour Stewart, Professor Schuster, Professor Stokes, Mr. G. Johnstone Stoney, Professor Sir H. E. Roscoe, Captain Abney, and Mr. G. J. Symons be reappointed a Committee for the purpose of considering the best methods of recording the direct intensity of Solar Radiation; that Professor Balfour Stewart be the Secretary, and that the unexpended sum of 20*l.* be placed at their disposal for the purpose.

That Professor Balfour Stewart (Secretary), Mr. Knox Laughton, Mr. G. J. Symons, and Mr. R. H. Scott be reappointed a Committee, with power to add to their number, for the purpose of co-operating with Mr. E. J. Lowe in his project of establishing a Meteorological Observatory near Chepstow on a permanent and scientific basis, and that the unexpended sum of 25*l.* be again placed at their disposal for the purpose.

That Professor G. H. Darwin, Sir W. Thomson, and Major Baird be a Committee for the purpose of preparing instructions for the practical work of Tidal Observation; that Professor Darwin be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Professors Balfour Stewart and Sir W. Thomson, Sir J. H. Lefroy, Sir Frederick Evans, Professor G. H. Darwin, Professor G. Chrystal, Professor S. J. Perry, Mr. C. H. Carpmael, Professor Schuster, Mr. G. M. Whipple, and Captain Creake be reappointed a Committee for the purpose of considering the best means of comparing and reducing Magnetic Observations; that Professor Balfour Stewart be the Secretary, and that the sum of 40*l.* be placed at their disposal for the purpose.

That Professor G. Forbes, Captain Abney, Dr. J. Hopkinson, Professor W. G. Adams, Professor G. C. Foster, Lord Rayleigh, Mr. Preece, Professor Schuster, Professor Dewar, Mr. A. Vernon Harcourt, Professor Ayrton, and Sir James Douglass be reappointed a Committee for the purpose of reporting on Standards of Light; that Professor G. Forbes be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professor Crum Brown, Mr. Milne-Home, Mr. John Murray, and Mr. Buchan be reappointed a Committee for the purpose of co-operating with the Scottish Meteorological Society in making meteorological observations on Ben Nevis; that Professor Crum Brown be the Secretary, and that the sum of 100*l.* be placed at their disposal for the purpose.

That Professors Armstrong, Lodge, and Sir William Thomson, Lord Rayleigh, Professors Schuster, Poynting, J. J. Thomson, Fitzgerald, Crum Brown, Ramsay, Frankland, Tilden, and Hartley, Captain Abney, Messrs. W. N. Shaw, H. B. Dixon, J. T. Bottomley, W. Crookes, and Shelford Bidwell, and Dr. Fleming be a Committee for the purpose of considering the subject of Electrolysis in its Physical and Chemical bearings; that Professor Armstrong be the Chemical Secretary and Professor Lodge the Physical Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professors McLeod and Ramsay and Mr. W. A. Shenstone be a Committee for the further investigation of the Influence of the Silent Discharge of Electricity on Oxygen and other gases; that Mr. W. A. Shenstone be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professors Williamson, Dewar, Frankland, Crum Brown, Odling, and Armstrong, Drs. Hugo Müller, A. G. Vernon Harcourt, F. R. Japp, and H. Forster Morley, and Messrs. C. E. Groves, J. Millar Thomson, V. H. Veley, and H. B. Dixon be reappointed a Committee for the purpose of drawing up a statement of the varieties of Chemical Names which have come into use, for indicating the causes which have led to their adoption, and for considering what can be done to bring about some convergence of the views on Chemical Nomenclature obtaining among English and foreign chemists; that Mr. H. B. Dixon be the Secretary, and that the sum of 5*l.* be placed at their disposal for the purpose.

That Mr. W. T. Blanford, Professor J. W. Judd, and Messrs. W. Carruthers, H. Woodward, and J. S. Gardner be reappointed a Committee for the purpose of reporting on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom; that Mr. J. S. Gardner be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Professor T. McK. Hughes, Dr. H. Hicks, Dr. H. Woodward, and Messrs. E. B. Luxmoore, P. Pennant, and Edwin Morgan be a Committee for the purpose of exploring the Caves of North Wales; that Dr. H. Hicks be the Secretary, and that the sum of 25*l.* be placed at their disposal for the purpose.

That Mr. R. Etheridge, Mr. T. Gray, and Professor John Milne be reappointed a Committee for the purpose of investigating the Volcanic Phenomena of Japan; that Professor John Milne be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Messrs. R. B. Grantham, C. E. De Rance, J. B. Redman, W. Topley, W. Whitaker, and J. W. Woodall, Major-General Sir A. Clarke, Admiral Sir E. Ommanney, Sir J. N. Douglass, Captain Sir F. J. O. Evans, Captain J. Parsons, Captain W. J. L. Wharton, Professor J. Prestwich, and Messrs. E. Easton, J. S. Valentine, and L. F. Vernon Harcourt be reappointed a Committee for the purpose of inquiring into the Rate of Erosion of the Sea-coasts of England and Wales, and the Influence of the Artificial Abstraction of Shingle or other Material in that

Action; that Messrs. De Rance and Topley be the Secretaries, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Messrs. H. Bauerman, F. W. Rudler, J. J. H. Teall, and H. J. Johnston-Lavis be reappointed a Committee for the purpose of investigating the Volcanic Phenomena of Vesuvius and its neighbourhood; that Mr. H. J. Johnston-Lavis be the Secretary, and that the sum of 30*l.* be placed at their disposal for the purpose.

That Dr. J. Evans, Professor W. J. Sollas, Dr. G. J. Hinde, and Messrs. W. Carruthers, R. B. Newton, J. J. H. Teall, F. W. Rudler, W. Topley, W. Whitaker, and E. Wethered be a Committee for the purpose of carrying on the Geological Record; that Mr. W. Topley be the Secretary, and that the sum of 100*l.* be placed at their disposal for the purpose.

That Mr. R. Etheridge, Dr. H. Woodward, and Professor T. R. Jones be reappointed a Committee for the purpose of reporting on the Fossil Phyllopoda of the Palæozoic Rocks; that Professor T. R. Jones be the Secretary, and that the sum of 15*l.* be placed at their disposal for the purpose.

That Mr. Stainton, Sir John Lubbock, and Mr. McLachlan be a Committee for the purpose of continuing a Record of Zoological Literature; that Mr. Stainton be the Secretary, and that the sum of 100*l.* be placed at their disposal for the purpose.

That Mr. John Murray, Professor Cossar Ewart, Professor Alleyne Nicholson, Professor McIntosh, Professor Young, Professor Struthers, and Professor McKendrick be reappointed a Committee for the purposes of a Marine Biological Station at Granton, Scotland; that Mr. John Murray be the Secretary, and that the sum of 75*l.* be placed at their disposal for the purpose.

That Professor Ray Lankester, Mr. P. L. Sclater, Professor M. Foster, Mr. A. Sedgwick, Professor A. M. Marshall, Professor A. C. Haddon, Professor Moseley, and Mr. Percy Sladen be reappointed a Committee for the purpose of arranging for the occasional occupation of a table at the Zoological Station at Naples; that Mr. Percy Sladen be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Professor Cleland, Professor McKendrick, Professor Ewart, Professor Stirling, Professor Bower, Dr. Cleghorn, and Professor McIntosh be a Committee for the purpose of continuing the Researches on Food Fishes and Invertebrates at the Marine Laboratory, St. Andrews; that Professor McIntosh be the Secretary, and that the sum of 75*l.* be placed at their disposal for the purpose.

That Mr. J. Cordeaux, Mr. J. A. Harvie-Brown, Professor Newton, Mr. W. Eagle Clarke, Mr. R. M. Barrington, and Mr. A. G. More be appointed a Committee for the purpose of obtaining (with the consent of the Master and Elder Brethren of the Trinity House and the Commissioners of Northern and Irish Lights) observations on Migration at Lighthouses and Lightvessels, and of reporting on the same; that Mr. J. Cordeaux be the Secretary, and that the sum of 30*l.* be placed at their disposal for the purpose.

That Professor Cleland, Professor McKendrick, and Dr. McGregor-Robertson be a Committee for the purpose of investigating the Mechanism of the Secretion of Urine; that Dr. McGregor-Robertson be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That General J. T. Walker, Sir J. H. Lefroy, Lieut.-Colonel Godwin-

Austen, Mr. W. T. Blanford, Mr. Sclater, Mr. Carruthers, Mr. Thiselton-Dyer, Professor Struthers, Mr. G. W. Bloxam, Mr. H. W. Bates, Lord Alfred Churchill, Mr. F. Galton, Mr. J. S. O'Halloran, Mr. Coutts Trotter, and Professor Moseley be a Committee for the purpose of furthering the Exploration of New Guinea, by making a grant to Mr. Forbes for the purposes of his Expedition; that Mr. H. W. Bates be the Secretary, and that the sum of 150*l.* be placed at their disposal for the purpose.

That General J. T. Walker, Sir J. H. Lefroy, Sir William Thomson, Mr. Alexander Buchan, Mr. J. Y. Buchanan, Mr. John Murray, Dr. Rae, Mr. H. W. Bates, and Captain W. J. Dawson be a Committee for the purpose of organising a systematic investigation of the Depth of the permanently Frozen Soil in the Polar Regions, its geographical limits, and relation to the present Pole of greatest cold; that Mr. H. W. Bates be the Secretary, and that the sum of 5*l.* be placed at their disposal for the purpose.

That Professor Sidgwick, Professor Foxwell, the Rev. W. Cunningham, and Professor Munro be a Committee for the purpose of inquiring into the Regulation of Wages under the Sliding Scales; that Professor Munro be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Mr. W. H. Barlow, Professor J. Thomson, Captain D. Galton, Mr. B. Baker, Professor W. C. Unwin, Professor A. B. W. Kennedy, Mr. C. Barlow, Mr. A. T. Atchison, and Professor H. S. Hele Shaw be a Committee for the purpose of obtaining information with reference to the Endurance of Metals under repeated and varying stresses, and the proper working stresses on Railway Bridges and other structures subject to varying loads; that Mr. A. T. Atchison be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

That Dr. Garson, Mr. Pengelly, Mr. F. W. Rudler, and Mr. G. W. Bloxam be a Committee for the purpose of investigating the Prehistoric Race in the Greek Islands; that Mr. Bloxam be the Secretary, and that the sum of 20*l.* be placed at their disposal for the purpose.

That Dr. E. B. Tylor, Dr. G. M. Dawson, General Sir J. H. Lefroy, Dr. Daniel Wilson, Mr. R. G. Haliburton, and Mr. George W. Bloxam be reappointed a Committee for the purpose of investigating and publishing reports on the physical characters, languages, and industrial and social condition of the North-Western Tribes of the Dominion of Canada; that Mr. Bloxam be the Secretary, and that the sum of 50*l.* be placed at their disposal for the purpose.

That Mr. Francis Galton, Dr. Beddoe, Mr. Brabrook, Professor Cunningham, Professor Flower, Mr. J. Park Harrison, Professor A. Macalister, Dr. Muirhead, Mr. F. W. Rudler, Professor Thane, and Dr. Garson be reappointed a Committee for the purpose of defining the Racial Characteristics of the Inhabitants of the British Isles; that Dr. Garson be the Secretary, and that the sum of 10*l.* be placed at their disposal for the purpose.

Not involving Grants of Money.

That Mr. James N. Shoolbred and Sir William Thomson be reappointed a Committee for the purpose of reducing and tabulating the Tidal Observations in the English Channel made with the Dover tide-gauge,

and of connecting them with observations made on the French coast; and that Mr. Shoolbred be the Secretary.

That Professor Barrett, Professor Fitzgerald, and Professor Balfour Stewart be a Committee for the purpose of reporting on the Molecular Phenomena attending the Magnetisation of Iron; and that Professor Barrett be the Secretary.

That Professor G. H. Darwin and Professor J. C. Adams be reappointed a Committee for the Harmonic Analysis of Tidal Observations; and that Professor Darwin be the Secretary.

That Mr. John Murray, Professor Schuster, Sir William Thomson, Professor Sir H. E. Roscoe, Professor A. S. Herschel, Captain W. de W. Abney, Professor Bonney, Mr. R. H. Scott, and Dr. J. H. Gladstone be reappointed a Committee for the purpose of investigating the practicability of collecting and identifying Meteoric Dust, and of considering the question of undertaking regular observations in various localities; and that Mr. Murray be the Secretary.

That Professors A. Johnson, Macgregor, J. B. Cherriman, and H. J. Bovey and Mr. C. Carpmael be reappointed a Committee for the purpose of promoting Tidal Observations in Canada; and that Professor Johnson be the Secretary.

That Professor Sylvester, Professor Cayley, and Professor Salmon be reappointed a Committee for the purpose of calculating Tables of the Fundamental Invariants of Algebraic Forms; and that Professor Cayley be the Secretary.

That Professors Everett and Sir William Thomson, Mr. G. J. Symons, Sir A. C. Ramsay, Dr. A. Geikie, Mr. J. Glaisher, Mr. Pengelly, Professor Edward Hull, Professor Prestwich, Dr. C. Le Neve Foster, Professor A. S. Herschel, Professor G. A. Lebour, Mr. A. B. Wynne, Mr. Galloway, Mr. Joseph Dickinson, Mr. G. F. Deacon, Mr. E. Wethered, and Mr. A. Strahan be reappointed a Committee for the purpose of investigating the Rate of Increase of Underground Temperature downwards in various Localities of Dry Land and under Water; and that Professor Everett be the Secretary.

That Professor Cayley, Sir William Thomson, Mr. James Glaisher, and Mr. J. W. L. Glaisher (Secretary) be reappointed a Committee for the purpose of calculating certain tables in the Theory of Numbers connected with the divisors of a number.

That Professors Tilden and Ramsay and Dr. W. W. J. Nicol be a Committee for the purpose of investigating the subject of Vapour Pressures and Refractive Indices of Salt Solutions; and that Dr. W. W. J. Nicol be the Secretary.

That Professors Ramsay, Tilden, Marshall, and W. L. Goodwin be a Committee for the purpose of investigating certain Physical Constants of Solution, especially the expansion of saline solutions; and that Professor W. L. Goodwin be the Secretary.

That Professors W. A. Tilden and H. E. Armstrong be a Committee for the purpose of investigating Isomeric Naphthalene Derivatives; and that Professor H. E. Armstrong be the Secretary.

That Professor Sir H. E. Roscoe, Mr. Lockyer, Professors Dewar, Liveing, Schuster, W. N. Hartley, and Wolcott Gibbs, Captain Abney, and Dr. Marshall Watts be a Committee for the purpose of preparing a new series of Wave-length Tables of the Spectra of the Elements; and that Dr. Marshall Watts be the Secretary.

That Professors Dewar and A. W. Williamson, Dr. Marshall Watts, Captain Abney, Dr. Johnstone Stoney, Professors W. N. Hartley, McLeod, Carey Foster, A. K. Huntington, Emerson Reynolds, Reinold, and Liveing, Lord Rayleigh, Professor Schuster, and Professor W. Chandler Roberts be a Committee for the purpose of reporting upon the present state of our knowledge of Spectrum Analysis; and that Professor W. Chandler Roberts be the Secretary.

That Professor E. Hull, Dr. H. W. Crosskey, Captain Douglas Galton, Professor J. Prestwich, and Messrs. James Glaisher, E. B. Marten, G. H. Morton, James Parker, W. Pengelly, James Plant, I. Roberts, Fox Strangways, T. S. Stooke, G. J. Symons, W. Topley, Tylden-Wright, E. Wethered, W. Whitaker, and C. E. De Rance be reappointed a Committee for the purpose of investigating the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Waters supplied to various towns and districts from these formations; and that Mr. De Rance be the Secretary.

That Professors J. Prestwich, W. Boyd Dawkins, T. McK. Hughes, and T. G. Bonney, Dr. H. W. Crosskey, and Messrs. C. E. De Rance, H. G. Fordham, J. E. Lee, D. Mackintosh, W. Pengelly, J. Plant, and R. H. Tiddeman be reappointed a Committee for the purpose of recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England, Wales, and Ireland, reporting other matters of interest connected with the same, and taking measures for their preservation; and that Dr. Crosskey be the Secretary.

That Sir A. Taylor, Professor Bayley Balfour, Dr. Crombie Brown, Dr. Cleghorn, and Sir John Lubbock be a Committee for the purpose of considering whether the condition of our Forests and Woodlands might not be improved by the establishment of a Forest School.

That Sir Joseph D. Hooker, Sir George Nares, Mr. John Murray, General J. T. Walker, Admiral Sir Leopold McClintock, Dr. W. B. Carpenter, Mr. Clements Markham, and Admiral Sir Erasmus Ommanney, be a Committee for the purpose of drawing attention to the desirability of further research in the Antarctic Regions, nearly half a century having elapsed since the last exploration; and that Admiral Sir Erasmus Ommanney be the Secretary.

That General J. T. Walker, Sir J. H. Lefroy, Sir William Thomson, Mr. Alexander Buchan, Mr. J. Y. Buchanan, Mr. John Murray, Mr. Francis Galton, Mr. H. W. Bates, and Mr. E. G. Ravenstein, with power to add to their number, be a Committee for the purpose of taking into consideration the combination of the Ordnance and Admiralty Surveys, and the production of a batho-hypsographical map of the British Islands; and that Mr. E. G. Ravenstein be the Secretary.

That General J. T. Walker, Sir William Thomson, Sir J. H. Lefroy, General R. Strachey, Professor A. S. Herschel, Professor G. Chrystal, Professor C. Niven, Professor J. H. Poynting, and Professor A. Schuster be a Committee for the purpose of inviting designs for a good Differential Gravity Meter in supersession of the pendulum, whereby satisfactory results may be obtained, at each station of observation, in a few hours, instead of the many days over which it is necessary to extend pendulum observations; and that Professor J. H. Poynting be the Secretary.

That Dr. J. H. Gladstone, Professor Armstrong, Mr. William Shaen, Mr. Stephen Bourne, Miss Lydia Becker, Sir John Lubbock, Dr. H. W. Crosskey, Sir Richard Temple, Sir Henry E. Roscoe, Mr. James

Heywood, and Professor N. Story Maskelyne be reappointed a Committee for the purpose of continuing the inquiries relating to the teaching of Science in Elementary Schools; and that Dr. J. H. Gladstone be the Secretary.

That the Corresponding Societies Committee, consisting of Mr. F. Galton, Professor Williamson, Captain Douglas Galton, Professor Boyd Dawkins, Sir Rawson Rawson, Dr. Garson, Mr. J. Evans, Mr. J. Hopkinson, Mr. Whitaker, Mr. Symons, Professor Meldola (Secretary), and General Pitt-Rivers, be reappointed.

That Mr. Mollison be requested to report on the present state of our knowledge of the Mathematical Theory of Thermal Conduction.

That Mr. P. T. Main be requested to draw up a Report on our experimental knowledge of the Properties of Matter with respect to volume, pressure, temperature, and specific heat.

That Mr. Glazebrook be requested to continue his Report on Optics.

That Professor J. J. Thomson be requested to continue his Report on Electrical Theories.

Communications ordered to be printed in extenso *in the Annual Report of the Association.*

Mr. Meldrum's paper, 'A Tabular Statement of the dates at which, and the localities where Pumice or Volcanic Dust was seen in the Indian Ocean' (with one plate).

Professor O. J. Lodge's paper 'On Electrolysis,' opening the discussion on Electrolysis.

Mr. Harker's paper 'On Slaty Cleavage.'

That Mr. Whitaker be requested to enlarge his List of Works on the Geology of Staffordshire by the addition of lists on Warwickshire and Worcestershire, and that the same be printed in full in the Report.

Mr. Stephen Bourne's paper 'On the use of Index Numbers in the Investigation of Trade Statistics.'

Mr. W. H. Preece's paper 'On the Strength of Telegraph Poles.'

Mr. A. S. Biggart's paper 'On the Forth Bridge Works,' with the necessary plates.

Mr. J. N. Shoolbred's paper 'On the Electric Lighting of the Forth Bridge.'

Mr. C. Barlow's paper 'On the Tay Bridge,' with the necessary plates.

Resolutions referred to the Council for Consideration, and Action if desirable.

That the Council be requested to reconsider the proposal of holding a General International Congress, and to report to the General Committee thereon at the next Meeting of the Association.

That the Council be requested to consider the desirability of admitting ladies as Officers of the Association, or as Members of the General or Sectional Committees.

That the Council be requested to consider the advisability of rendering the special Reports of the Association more accessible to the scientific public by placing them on sale in separate form.

That the printed Reports on Special Subjects be offered for sale to

the general public at the time of the Meeting, or as soon afterwards as possible.

That the Council be requested to so modify the Rules of the Association as to permit of a Sectional Meeting being held at an earlier hour than eleven, and the Sectional Committee previously, due notice being given to the Section on the previous day.

That a memorial be presented to H.M. Government requesting them to enlarge the existing Agricultural Department of the Privy Council, with the view of concentrating all administrative functions relating to Agriculture in one fully-equipped Board and Department of Agriculture.

That the Council be requested to consider and take steps, if they think it desirable, to memorialise the Government to undertake the more systematic collection and annual publication of Statistics of Wages, and a periodical industrial census.

That a memorial be presented to H.M. Government in favour of the establishment of a National School of Forestry.

Synopsis of Grants of Money appropriated to Scientific Purposes by the General Committee at the Aberdeen Meeting in September 1885. The Names of the Members entitled to call on the General Treasurer for the respective Grants are prefixed.

Mathematics and Physics.

	£	s.	d.
*Foster, Professor G. Carey.—Electrical Standards	40	0	0
*Stewart, Professor Balfour.—Solar Radiation	20	0	0
*Stewart, Professor Balfour.—Meteorological Observations at Chepstow	25	0	0
Darwin, Professor G. H.—Instructions for Tidal Observations	50	0	0
*Stewart, Professor Balfour.—Comparing and reducing Magnetic Observations	40	0	0
*Forbes, Professor G.—Standards of Light	20	0	0
*Brown, Professor Crum.—Ben Nevis Observatory	100	0	0
*Armstrong, Professor.—Physical and Chemical bearings of Electrolysis	20	0	0

Chemistry.

M'Leod, Professor.—Silent discharge of Electricity into atmosphere	20	0	0
*Williamson, Professor A. W.—Chemical Nomenclature	5	0	0

Geology.

*Blanford, Mr. W. T.—Fossil plants of the Tertiary and Secondary Beds	20	0	0
Hughes, Professor T. McK.—Caves of North Wales	25	0	0
*Etheridge, Mr. R.—Volcanic Phenomena in Japan	50	0	0
*Grantham, R. B.—Erosion of Sea Coasts	20	0	0
*Bauerman, Mr. H.—Volcanic Phenomena of Vesuvius	30	0	0
*Evans, Dr. J.—Geological Record	100	0	0
*Etheridge, Mr. R.—Fossil Phyllopoda	15	0	0
Carried forward	£600	0	0

* Reappointed.

	£	s.	d.
Brought forward	600	0	0
Biology.			
*Stanton, Mr. H. T.—Zoological Record	100	0	0
*Murray, Mr. J.—Marine Biological Station at Grantham ...	75	0	0
*Lankester, Professor Ray.—Zoological Station at Naples ...	50	0	0
Cleland, Professor.—Researches in Food Fishes and Invertebrata at St. Andrews	75	0	0
*Cordeaux, Mr. J.—Migration of Birds	30	0	0
Cleland, Professor.—Mechanism of Secretion of Urine	10	0	0
Geography.			
Walker, General J. T.—New Guinea Exploration	150	0	0
Walker, General J. T.—Investigation into depth of permanently frozen soil in Polar Regions	5	0	0
Economic Science and Statistics.			
Sidgwick, Professor.—Regulation of Wages under sliding scales	10	0	0
Mechanics.			
Barlow, Mr. W. H.—Effect of varying stresses on metals ...	10	0	0
Anthropology.			
Garson, Dr.—Investigation into a pre-historic race in the Greek Islands	20	0	0
*Tylor, Dr. E. B.—Investigation into North-Western Tribes of Canada	50	0	0
*Galton, Mr. F.—Racial characteristics in British Isles	10	0	0
	£1195	0	0

* Reappointed.

The Annual Meeting in 1886.

The Meeting at Birmingham will commence on Wednesday, September 1.

Place of Meeting in 1887.

The Annual Meeting of the Association will be held at Manchester.

General Statement of Sums which have been paid on account of Grants for Scientific Purposes.

	£	s.	d.
1834.			
Tide Discussions	20	0	0
1835.			
Tide Discussions	62	0	0
British Fossil Ichthyology	105	0	0
	£167	0	0
1836.			
Tide Discussions	163	0	0
British Fossil Ichthyology	105	0	0
Thermometric Observations, &c.	50	0	0
Experiments on long-continued Heat	17	1	0
Rain-Gauges	9	13	0
Refraction Experiments	15	0	0
Lunar Nutation	60	0	0
Thermometers	15	6	0
	£435	0	0
1837.			
Tide Discussions	284	1	0
Chemical Constants	24	13	6
Lunar Nutation	70	0	0
Observations on Waves	100	12	0
Tides at Bristol	150	0	0
Meteorology and Subterranean Temperature	93	3	0
Vitrification Experiments	150	0	0
Heart Experiments	8	4	6
Barometric Observations	30	0	0
Barometers	11	18	6
	£922	12	6
1838.			
Tide Discussions	29	0	0
British Fossil Fishes	100	0	0
Meteorological Observations and Anemometer (construction)	100	0	0
Cast Iron (Strength of)	60	0	0
Animal and Vegetable Substances (Preservation of)	19	1	10
Railway Constants	41	12	10
Bristol Tides	50	0	0
Growth of Plants	75	0	0
Mud in Rivers	3	6	6
Education Committee	50	0	0
Heart Experiments	5	3	0
Land and Sea Level	267	8	7
Steam-vessels	100	0	0
Meteorological Committee	31	9	5
	£932	2	2
1839.			
Fossil Ichthyology	110	0	0
Meteorological Observations at Plymouth, &c.	63	10	0
Mechanism of Waves	144	2	0
Bristol Tides	35	18	6
Meteorology and Subterranean Temperature	21	11	0
Vitrification Experiments	9	4	7
Cast-Iron Experiments	103	0	0
Railway Constants	28	7	2
Land and Sea Level	274	1	4
Steam-vessels' Engines	100	0	0
Stars in Histoire Céleste	171	18	6
Stars in Lacaille	11	0	0
Stars in R.A.S. Catalogue	166	16	6
Animal Secretions	10	10	0
Steam Engines in Cornwall	50	0	0
Atmospheric Air	16	1	0
Cast and Wrought Iron	40	0	0
Heat on Organic Bodies	3	0	0
Gases on Solar Spectrum	22	0	0
Hourly Meteorological Observations, Inverness and Kingussie	49	7	8
Fossil Reptiles	118	2	9
Mining Statistics	50	0	0
	£1595	11	0
1840.			
Bristol Tides	100	0	0
Subterranean Temperature	13	13	6
Heart Experiments	18	19	0
Lungs Experiments	8	13	0
Tide Discussions	50	0	0
Land and Sea Level	6	11	1
Stars (Histoire Céleste)	242	10	0
Stars (Lacaille)	4	15	0
Stars (Catalogue)	264	0	0
Atmospheric Air	15	15	0
Water on Iron	10	0	0
Heat on Organic Bodies	7	0	0
Meteorological Observations	52	17	6
Foreign Scientific Memoirs	112	1	6
Working Population	100	0	0
School Statistics	50	0	0
Forms of Vessels	184	7	0
Chemical and Electrical Phenomena	40	0	0
Meteorological Observations at Plymouth	80	0	0
Magnetical Observations	185	13	9
	£1546	16	4
1841.			
Observations on Waves	30	0	0
Meteorology and Subterranean Temperature	8	8	0
Actinometers	10	0	0
Earthquake Shocks	17	7	0
Acrid Poisons	6	0	0
Veins and Absorbents	3	0	0
Mud in Rivers	5	0	0

	£	s.	d.
Marine Zoology	15	12	8
Skeleton Maps	20	0	0
Mountain Barometers	6	18	6
Stars (Histoire Céleste)	185	0	0
Stars (Lacaille)	79	5	0
Stars (Nomenclature of)	17	19	6
Stars (Catalogue of)	40	0	0
Water on Iron	50	0	0
Meteorological Observations at Inverness	20	0	0
Meteorological Observations (reduction of)	25	0	0
Fossil Reptiles	50	0	0
Foreign Memoirs	62	0	6
Railway Sections	38	1	0
Forms of Vessels	193	12	0
Meteorological Observations at Plymouth	55	0	0
Magnetical Observations	61	18	8
Fishes of the Old Red Sandstone	100	0	0
Tides at Leith	50	0	0
Anemometer at Edinburgh	69	1	10
Tabulating Observations	9	6	3
Races of Men	5	0	0
Radiate Animals	2	0	0
	£1235	10	11

1842.

	£	s.	d.
Dynamometric Instruments	113	11	2
Anoplura Britanniæ	52	12	0
Tides at Bristol	59	8	0
Gases on Light	30	14	7
Chronometers	26	17	6
Marine Zoology	1	5	0
British Fossil Mammalia	100	0	0
Statistics of Education	20	0	0
Marine Steam-vessels' Engines	28	0	0
Stars (Histoire Céleste)	59	0	0
Stars (Brit. Assoc. Cat. of)	110	0	0
Railway Sections	161	10	0
British Belemnites	50	0	0
Fossil Reptiles (publication of Report)	210	0	0
Forms of Vessels	180	0	0
Galvanic Experiments on Rocks	5	8	6
Meteorological Experiments at Plymouth	68	0	0
Constant Indicator and Dynamometric Instruments	90	0	0
Force of Wind	10	0	0
Light on Growth of Seeds	8	0	0
Vital Statistics	50	0	0
Vegetative Power of Seeds	8	1	11
Questions on Human Race	7	9	0
	£1449	17	8

1843.

	£	s.	d.
Revision of the Nomenclature of Stars	2	0	0
Reduction of Stars, British Association Catalogue	25	0	0
Anomalous Tides, Frith of Forth	120	0	0
Hourly Meteorological Observations at Kingussie and Inverness	77	12	8
Meteorological Observations at Plymouth	55	0	0
Whewell's Meteorological Anemometer at Plymouth	10	0	0
Meteorological Observations, Osler's Anemometer at Plymouth	20	0	0
Reduction of Meteorological Observations	30	0	0
Meteorological Instruments and Gratuities	39	6	0
Construction of Anemometer at Inverness	56	12	2
Magnetic Co-operation	10	8	10
Meteorological Recorder for Kew Observatory	50	0	0
Action of Gases on Light	18	16	1
Establishment at Kew Observatory, Wages, Repairs Furniture, and Sundries	133	4	7
Experiments by Captive Balloons	81	8	0
Oxidation of the Rails of Railways	20	0	0
Publication of Report on Fossil Reptiles	40	0	0
Coloured Drawings of Railway Sections	147	18	3
Registration of Earthquake Shocks	30	0	0
Report on Zoological Nomenclature	10	0	0
Uncovering Lower Red Sandstone near Manchester	4	4	6
Vegetative Power of Seeds	5	3	8
Marine Testacea (Habits of)	10	0	0
Marine Zoology	10	0	0
Marine Zoology	2	14	11
Preparation of Report on British Fossil Mammalia	100	0	0
Physiological Operations of Medicinal Agents	20	0	0
Vital Statistics	36	5	8
Additional Experiments on the Forms of Vessels	70	0	0
Additional Experiments on the forms of Vessels	100	0	0
Reduction of Experiments on the Forms of Vessels	100	0	0
Morin's Instrument and Constant Indicator	69	14	10
Experiments on the Strength of Materials	60	0	0
	£1565	10	2

	£	s.	d.
1844.			
Meteorological Observations at Kingussie and Inverness	12	0	0
Completing Observations at Plymouth	35	0	0
Magnetic and Meteorological Co-operation	25	8	4
Publication of the British Association Catalogue of Stars	35	0	0
Observations on Tides on the East Coast of Scotland	100	0	0
Revision of the Nomenclature of Stars 1842	2	9	6
Maintaining the Establishment in Kew Observatory	117	17	3
Instruments for Kew Observatory	56	7	3
Influence of Light on Plants	10	0	0
Subterraneous Temperature in Ireland	5	0	0
Coloured Drawings of Railway Sections	15	17	6
Investigation of Fossil Fishes of the Lower Tertiary Strata	100	0	0
Registering the Shocks of Earthquakes 1842	23	11	10
Structure of Fossil Shells	20	0	0
Radiata and Mollusca of the Ægean and Red Seas 1842	100	0	0
Geographical Distributions of Marine Zoology......1842	0	10	0
Marine Zoology of Devon and Cornwall	10	0	0
Marine Zoology of Corfu	10	0	0
Experiments on the Vitality of Seeds	9	0	0
Experiments on the Vitality of Seeds 1842	8	7	3
Exotic Anoplura	15	0	0
Strength of Materials	100	0	0
Completing Experiments on the Forms of Ships	100	0	0
Inquiries into Asphyxia	10	0	0
Investigations on the Internal Constitution of Metals	50	0	0
Constant Indicator and Morin's Instrument 1842	10	0	0
	£981	12	8
1845.			
Publication of the British Association Catalogue of Stars	351	14	6
Meteorological Observations at Inverness	30	18	11
Magnetic and Meteorological Co-operation	16	16	8
Meteorological Instruments at Edinburgh	18	11	9
Reduction of Anemometrical Observations at Plymouth	25	0	0
Electrical Experiments at Kew Observatory	43	17	8
Maintaining the Establishment in Kew Observatory	149	15	0
For Kreil's Barometrograph	25	0	0
Gases from Iron Furnaces	50	0	0
The Actinograph	15	0	0
Microscopic Structure of Shells	20	0	0
Exotic Anoplura 1843	10	0	0
Vitality of Seeds 1843	2	0	7
Vitality of Seeds 1844	7	0	0
Marine Zoology of Cornwall	10	0	0
Physiological Action of Medicines	20	0	0
Statistics of Sickness and Mortality in York	20	0	0
Earthquake Shocks 1843	15	14	8
	£831	9	9
1846.			
British Association Catalogue of Stars 1844	211	15	0
Fossil Fishes of the London Clay	100	0	0
Computation of the Gaussian Constants for 1829	50	0	0
Maintaining the Establishment at Kew Observatory	146	16	7
Strength of Materials	60	0	0
Researches in Asphyxia	6	16	2
Examination of Fossil Shells	10	0	0
Vitality of Seeds 1844	2	15	10
Vitality of Seeds 1845	7	12	3
Marine Zoology of Cornwall	10	0	0
Marine Zoology of Britain	10	0	0
Exotic Anoplura 1844	25	0	0
Expenses attending Anemometers	11	7	6
Anemometers' Repairs	2	3	6
Atmospheric Waves	3	3	3
Captive Balloons 1844	8	19	8
Varieties of the Human Race 1844	7	6	3
Statistics of Sickness and Mortality in York	12	0	0
	£685	16	0
1847.			
Computation of the Gaussian Constants for 1829	50	0	0
Habits of Marine Animals	10	0	0
Physiological Action of Medicines	20	0	0
Marine Zoology of Cornwall	10	0	0
Atmospheric Waves	6	9	3
Vitality of Seeds	4	7	7
Maintaining the Establishment at Kew Observatory	107	8	6
	£208	5	4

	£	s.	d.
1848.			
Maintaining the Establishment at Kew Observatory	171	15	11
Atmospheric Waves	3	10	9
Vitality of Seeds	9	15	0
Completion of Catalogue of Stars	70	0	0
On Colouring Matters	5	0	0
On Growth of Plants	15	0	0
	£275	1	8
1849.			
Electrical Observations at Kew Observatory	50	0	0
Maintaining the Establishment at ditto	76	2	5
Vitality of Seeds	5	8	1
On Growth of Plants	5	0	0
Registration of Periodical Phenomena	10	0	0
Bill on Account of Anemometrical Observations	13	9	0
	£159	19	6
1850.			
Maintaining the Establishment at Kew Observatory	255	18	0
Transit of Earthquake Waves	50	0	0
Periodical Phenomena	15	0	0
Meteorological Instruments, Azores	25	0	0
	£345	18	0
1851			
Maintaining the Establishment at Kew Observatory (includes part of grant in 1849)	309	2	2
Theory of Heat	20	1	1
Periodical Phenomena of Animals and Plants	5	0	0
Vitality of Seeds	5	6	4
Influence of Solar Radiation	30	0	0
Ethnological Inquiries	12	0	0
Researches on Annelida	10	0	0
	£391	9	7
1852.			
Maintaining the Establishment at Kew Observatory (including balance of grant for 1850)	233	17	8
Experiments on the Conduction of Heat	5	2	9
Influence of Solar Radiations	20	0	0
Geological Map of Ireland	15	0	0
Researches on the British Annelida	10	0	0
Vitality of Seeds	10	6	2
Strength of Boiler Plates	10	0	0
	£304	6	7
1853.			
Maintaining the Establishment at Kew Observatory	165	0	0
Experiments on the Influence of Solar Radiation	15	0	0
Researches on the British Annelida	10	0	0
Dredging on the East Coast of Scotland	10	0	0
Ethnological Queries	5	0	0
	£205	0	0
1854.			
Maintaining the Establishment at Kew Observatory (including balance of former grant)	330	15	4
Investigations on Flax	11	0	0
Effects of Temperature on Wrought Iron	10	0	0
Registration of Periodical Phenomena	10	0	0
British Annelida	10	0	0
Vitality of Seeds	5	2	3
Conduction of Heat	4	2	0
	£380	19	7
1855.			
Maintaining the Establishment at Kew Observatory	425	0	0
Earthquake Movements	10	0	0
Physical Aspect of the Moon	11	8	5
Vitality of Seeds	10	7	11
Map of the World	15	0	0
Ethnological Queries	5	0	0
Dredging near Belfast	4	0	0
	£480	16	4
1856.			
Maintaining the Establishment at Kew Observatory:— 1854.........£ 75 0 0; 1855.........£500 0 0	575	0	0
Strickland's Ornithological Synonyms	100	0	0
Dredging and Dredging Forms	9	13	0
Chemical Action of Light	20	0	0
Strength of Iron Plates	10	0	0
Registration of Periodical Phenomena	10	0	0
Propagation of Salmon	10	0	0
	£734	13	9
1857.			
Maintaining the Establishment at Kew Observatory	350	0	0
Earthquake Wave Experiments	40	0	0
Dredging near Belfast	10	0	0
Dredging on the West Coast of Scotland	10	0	0

	£	s.	d.
Investigations into the Mollusca of California	10	0	0
Experiments on Flax	5	0	0
Natural History of Madagascar	20	0	0
Researches on British Annelida	25	0	0
Report on Natural Products imported into Liverpool	10	0	0
Artificial Propagation of Salmon	10	0	0
Temperature of Mines	7	8	0
Thermometers for Subterranean Observations	5	7	4
Life-boats	5	0	0
	£507	15	4

1858.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Earthquake Wave Experiments	25	0	0
Dredging on the West Coast of Scotland	10	0	0
Dredging near Dublin	5	0	0
Vitality of Seeds	5	5	0
Dredging near Belfast	18	13	2
Report on the British Annelida	25	0	0
Experiments on the production of Heat by Motion in Fluids	20	0	0
Report on the Natural Products imported into Scotland	10	0	0
	£618	18	2

1859.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Dredging near Dublin	15	0	0
Osteology of Birds	50	0	0
Irish Tunicata	5	0	0
Manure Experiments	20	0	0
British Medusidæ	5	0	0
Dredging Committee	5	0	0
Steam-vessels' Performance	5	0	0
Marine Fauna of South and West of Ireland	10	0	0
Photographic Chemistry	10	0	0
Lanarkshire Fossils	20	0	1
Balloon Ascents	39	11	0
	£684	11	1

1860.

	£	s.	d.
Maintaining the Establishment at Kew Observatory	500	0	0
Dredging near Belfast	16	6	0
Dredging in Dublin Bay	15	0	0
Inquiry into the Performance of Steam-vessels	124	0	0
Explorations in the Yellow Sandstone of Dura Don	20	0	0
Chemico-mechanical Analysis of Rocks and Minerals	25	0	0
Researches on the Growth of Plants	10	0	0
Researches on the Solubility of Salts	30	0	0
Researches on the Constituents of Manures	25	0	0
Balance of Captive Balloon Accounts	1	13	6
	£766	19	6

1861.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	500	0	0
Earthquake Experiments	25	0	0
Dredging North and East Coasts of Scotland	23	0	0
Dredging Committee :— 1860......£50 0 0; 1861......£22 0 0	72	0	0
Excavations at Dura Den	20	0	0
Solubility of Salts	20	0	0
Steam-vessel Performance	150	0	0
Fossils of Lesmahago	15	0	0
Explorations at Uriconium	20	0	0
Chemical Alloys	20	0	0
Classified Index to the Transactions	100	0	0
Dredging in the Mersey and Dee	5	0	0
Dip Circle	30	0	0
Photoheliographic Observations	50	0	0
Prison Diet	20	0	0
Gauging of Water	10	0	0
Alpine Ascents	6	5	10
Constituents of Manures	25	0	0
	£1111	5	10

1862.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	500	0	0
Patent Laws	21	6	0
Mollusca of N.-W. of America	10	0	0
Natural History by Mercantile Marine	5	0	0
Tidal Observations	25	0	0
Photoheliometer at Kew	40	0	0
Photographic Pictures of the Sun	150	0	0
Rocks of Donegal	25	0	0
Dredging Durham and Northumberland	25	0	0
Connexion of Storms	20	0	0
Dredging North-east Coast of Scotland	6	9	6
Ravages of Teredo	3	11	0
Standards of Electrical Resistance	50	0	0
Railway Accidents	10	0	0
Balloon Committee	200	0	0
Dredging Dublin Bay	10	0	0

	£	s.	d.
Dredging the Mersey	5	0	0
Prison Diet	20	0	0
Gauging of Water	12	10	0
Steamships' Performance	150	0	0
Thermo-Electric Currents	5	0	0
	£1293	16	6

1863.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Balloon Committee deficiency	70	0	0
Balloon Ascents (other expenses)	25	0	0
Entozoa	25	0	0
Coal Fossils	20	0	0
Herrings	20	0	0
Granites of Donegal	5	0	0
Prison Diet	20	0	0
Vertical Atmospheric Movements	13	0	0
Dredging Shetland	50	0	0
Dredging North-east coast of Scotland	25	0	0
Dredging Northumberland and Durham	17	3	10
Dredging Committee superintendence	10	0	0
Steamship Performance	100	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Volcanic Temperature	100	0	0
Bromide of Ammonium	8	0	0
Electrical Standards	100	0	0
Electrical Construction and Distribution	40	0	0
Luminous Meteors	17	0	0
Kew Additional Buildings for Photoheliograph	100	0	0
Thermo-Electricity	15	0	0
Analysis of Rocks	8	0	0
Hydroida	10	0	0
	£1608	3	10

1864.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Coal Fossils	20	0	0
Vertical Atmospheric Movements	20	0	0
Dredging Shetland	75	0	0
Dredging Northumberland	25	0	0
Balloon Committee	200	0	0
Carbon under pressure	10	0	0
Standards of Electric Resistance	100	0	0
Analysis of Rocks	10	0	0
Hydroida	10	0	0
Askham's Gift	50	0	0
Nitrite of Amyle	10	0	0
Nomenclature Committee	5	0	0
Rain-Gauges	19	15	8
Cast-Iron Investigation	20	0	0
Tidal Observations in the Humber	50	0	0
Spectral Rays	45	0	0
Luminous Meteors	20	0	0
	£1289	15	8

1865.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Balloon Committee	100	0	0
Hydroida	13	0	0
Rain-Gauges	30	0	0
Tidal Observations in the Humber	6	8	0
Hexylic Compounds	20	0	0
Amyl Compounds	20	0	0
Irish Flora	25	0	0
American Mollusca	3	9	0
Organic Acids	20	0	0
Lingula Flags Excavation	10	0	0
Eurypterus	50	0	0
Electrical Standards	100	0	0
Malta Caves Researches	30	0	0
Oyster Breeding	25	0	0
Gibraltar Caves Researches	150	0	0
Kent's Hole Excavations	100	0	0
Moon's Surface Observations	35	0	0
Marine Fauna	25	0	0
Dredging Aberdeenshire	25	0	0
Dredging Channel Islands	50	0	0
Zoological Nomenclature	5	0	0
Resistance of Floating Bodies in Water	100	0	0
Bath Waters Analysis	8	10	10
Luminous Meteors	40	0	0
	£1591	7	10

1866.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	64	13	4
Balloon Committee	50	0	0
Metrical Committee	50	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	16	0	0
Alum Bay Fossil Leaf-Bed	15	0	0
Luminous Meteors	50	0	0
Lingula Flags Excavation	20	0	0
Chemical Constitution of Cast Iron	50	0	0
Amyl Compounds	25	0	0
Electrical Standards	100	0	0
Malta Caves Exploration	30	0	0
Kent's Hole Exploration	200	0	0
Marine Fauna, &c., Devon and Cornwall	25	0	0
Dredging Aberdeenshire Coast	25	0	0
Dredging Hebrides Coast	50	0	0
Dredging the Mersey	5	0	0
Resistance of Floating Bodies in Water	50	0	0
Polycyanides of Organic Radicals	29	0	0

	£	s.	d.
Rigor Mortis	10	0	0
Irish Annelida	15	0	0
Catalogue of Crania	50	0	0
Didine Birds of Mascarene Islands	50	0	0
Typical Crania Researches	30	0	0
Palestine Exploration Fund	100	0	0
	£1750	13	4

1867.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Meteorological Instruments, Palestine	50	0	0
Lunar Committee	120	0	0
Metrical Committee	30	0	0
Kent's Hole Explorations	100	0	0
Palestine Explorations	50	0	0
Insect Fauna, Palestine	30	0	0
British Rainfall	50	0	0
Kilkenny Coal Fields	25	0	0
Alum Bay Fossil Leaf-Bed	25	0	0
Luminous Meteors	50	0	0
Bournemouth, &c., Leaf-Beds	30	0	0
Dredging Shetland	75	0	0
Steamship Reports Condensation	100	0	0
Electrical Standards	100	0	0
Ethyl and Methyl series	25	0	0
Fossil Crustacea	25	0	0
Sound under Water	24	4	0
North Greenland Fauna	75	0	0
Do. Plant Beds	100	0	0
Iron and Steel Manufacture	25	0	0
Patent Laws	30	0	0
	£1739	4	0

1868.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	120	0	0
Metrical Committee	50	0	0
Zoological Record	100	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	100	0	0
British Rainfall	50	0	0
Luminous Meteors	50	0	0
Organic Acids	60	0	0
Fossil Crustacea	25	0	0
Methyl Series	25	0	0
Mercury and Bile	25	0	0
Organic Remains in Limestone Rocks	25	0	0
Scottish Earthquakes	20	0	0
Fauna, Devon and Cornwall	30	0	0
British Fossil Corals	50	0	0
Bagshot Leaf-Beds	50	0	0
Greenland Explorations	100	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Secondary Reptiles, &c.	30	0	0
British Marine Invertebrate Fauna	100	0	0
	£1940	0	0

1869.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Lunar Committee	50	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Gases in Deep-well Water	25	0	0
British Rainfall	50	0	0
Thermal Conductivity of Iron, &c.	30	0	0
Kent's Hole Explorations	150	0	0
Steamship Performances	30	0	0
Chemical Constitution of Cast Iron	80	0	
Iron and Steel Manufacture	100	0	0
Methyl Series	30	0	0
Organic Remains in Limestone Rocks	10	0	0
Earthquakes in Scotland	10	0	0
British Fossil Corals	50	0	0
Bagshot Leaf-Beds	30	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	30	0	0
Spectroscopic Investigations of Animal Substances	5	0	0
Organic Acids	12	0	0
Kiltorcan Fossils	20	0	0
Chemical Constitution and Physiological Action Relations	15	0	0
Mountain Limestone Fossils	25	0	0
Utilization of Sewage	10	0	0
Products of Digestion	10	0	0
	£1622	0	0

1870.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Metrical Committee	25	0	0
Zoological Record	100	0	0
Committee on Marine Fauna	20	0	0
Ears in Fishes	10	0	0
Chemical Nature of Cast Iron	80	0	0
Luminous Meteors	30	0	0
Heat in the Blood	15	0	0
British Rainfall	100	0	0
Thermal Conductivity of Iron, &c.	20	0	0
British Fossil Corals	50	0	0
Kent's Hole Explorations	150	0	0
Scottish Earthquakes	4	0	0
Bagshot Leaf-Beds	15	0	0
Fossil Flora	25	0	0
Tidal Observations	100	0	0
Underground Temperature	50	0	0
Kiltorcan Quarries Fossils	20	0	0

	£	s.	d.
Mountain Limestone Fossils	25	0	0
Utilization of Sewage	50	0	0
Organic Chemical Compounds	30	0	0
Onny River Sediment	3	0	0
Mechanical Equivalent of Heat..............................	50	0	0
	£1572	0	0

1871.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	600	0	0
Monthly Reports of Progress in Chemistry	100	0	0
Metrical Committee............	25	0	0
Zoological Record...............	100	0	0
Thermal Equivalents of the Oxides of Chlorine	10	0	0
Tidal Observations	100	0	0
Fossil Flora	25	0	0
Luminous Meteors	30	0	0
British Fossil Corals	25	0	0
Heat in the Blood...............	7	2	6
British Rainfall..................	50	0	0
Kent's Hole Explorations ...	150	0	0
Fossil Crustacea	25	0	0
Methyl Compounds	25	0	0
Lunar Objects	20	0	0
Fossil Coral Sections, for Photographing	20	0	0
Bagshot Leaf-Beds	20	0	0
Moab Explorations	100	0	0
Gaussian Constants	40	0	0
	£1472	2	6

1872.

	£	s.	d.
Maintaining the Establishment of Kew Observatory	300	0	0
Metrical Committee............	75	0	0
Zoological Record...............	100	0	0
Tidal Committee	200	0	0
Carboniferous Corals	25	0	0
Organic Chemical Compounds	25	0	0
Exploration of Moab............	100	0	0
Terato-Embryological Inquiries	10	0	0
Kent's Cavern Exploration..	100	0	0
Luminous Meteors	20	0	0
Heat in the Blood...............	15	0	0
Fossil Crustacea	25	0	0
Fossil Elephants of Malta ...	25	0	0
Lunar Objects	20	0	0
Inverse Wave-Lengths.........	20	0	0
British Rainfall..................	100	0	0
Poisonous Substances Antagonism..............................	10	0	0
Essential Oils, Chemical Constitution, &c.	40	0	0
Mathematical Tables	50	0	0
Thermal Conductivity of Metals	25	0	0
	£1285	0	0

1873.

	£	s.	d.
Zoological Record...............	100	0	0
Chemistry Record...............	200	0	0
Tidal Committee	400	0	0
Sewage Committee	100	0	0
Kent's Cavern Exploration...	150	0	0
Carboniferous Corals	25	0	0
Fossil Elephants	25	0	0
Wave-Lengths	150	0	0
British Rainfall..................	100	0	0
Essential Oils.....................	30	0	0
Mathematical Tables	100	0	0
Gaussian Constants	10	0	0
Sub-Wealden Explorations...	25	0	0
Underground Temperature...	150	0	0
Settle Cave Exploration	50	0	0
Fossil Flora, Ireland............	20	0	0
Timber Denudation and Rainfall	20	0	0
Luminous Meteors...............	30	0	0
	£1685	0	0

1874.

	£	s.	d.
Zoological Record...............	100	0	0
Chemistry Record...............	100	0	0
Mathematical Tables	100	0	0
Elliptic Functions...............	100	0	0
Lightning Conductors	10	0	0
Thermal Conductivity of Rocks	10	0	0
Anthropological Instructions, &c.	50	0	0
Kent's Cavern Exploration...	150	0	0
Luminous Meteors	30	0	0
Intestinal Secretions	15	0	0
British Rainfall..................	100	0	0
Essential Oils.....................	10	0	0
Sub-Wealden Explorations...	25	0	0
Settle Cave Exploration	50	0	0
Mauritius Meteorological Research	100	0	0
Magnetization of Iron	20	0	0
Marine Organisms...............	30	0	0
Fossils, North-West of Scotland	2	10	0
Physiological Action of Light	20	0	0
Trades Unions	25	0	0
Mountain Limestone-Corals	25	0	0
Erratic Blocks	10	0	0
Dredging, Durham and Yorkshire Coasts	28	5	0
High Temperature of Bodies	30	0	0
Siemens's Pyrometer	3	6	0
Labyrinthodonts of Coal-Measures.......................	7	15	0
	£1151	16	0

1875.

	£	s.	d.
Elliptic Functions	100	0	0
Magnetization of Iron	20	0	0
British Rainfall..................	120	0	0
Luminous Meteors	30	0	0
Chemistry Record...............	100	0	0

	£	s.	d.
Specific Volume of Liquids...	25	0	0
Estimation of Potash and Phosphoric Acid..............	10	0	0
Isometric Cresols	20	0	0
Sub-Wealden Explorations ...	100	0	0
Kent's Cavern Exploration...	100	0	0
Settle Cave Exploration	50	0	0
Earthquakes in Scotland	15	0	0
Underground Waters	10	0	0
Development of Myxinoid Fishes	20	0	0
Zoological Record..............	100	0	0
Instructions for Travellers ...	20	0	0
Intestinal Secretions	20	0	0
Palestine Exploration	100	0	0
	£960	0	0

1876.

	£	s.	d.
Printing Mathematical Tables	159	4	2
British Rainfall.................	100	0	0
Ohm's Law.......................	9	15	0
Tide Calculating Machine ...	200	0	0
Specific Volume of Liquids...	25	0	0
Isomeric Cresols	10	0	0
Action of Ethyl Bromobutyrate on Ethyl Sodacetoacetate..........................	5	0	0
Estimation of Potash and Phosphoric Acid..............	13	0	0
Exploration of Victoria Cave, Settle	100	0	0
Geological Record..............	100	0	0
Kent's Cavern Exploration ...	100	0	0
Thermal Conductivities of Rocks	10	0	0
Underground Waters	10	0	0
Earthquakes in Scotland......	1	10	0
Zoological Record..............	100	0	0
Close Time	5	0	0
Physiological Action of Sound	25	0	0
Zoological Station..............	75	0	0
Intestinal Secretions	15	0	0
Physical Characters of Inhabitants of British Isles......	13	15	0
Measuring Speed of Ships ...	10	0	0
Effect of Propeller on turning of Steam Vessels	5	0	0
	£1092	4	2

1877.

	£	s.	d.
Liquid Carbonic Acids in Minerals	20	0	0
Elliptic Functions	250	0	0
Thermal Conductivity of Rocks	9	11	7
Zoological Record..............	100	0	0
Kent's Cavern	100	0	0
Zoological Station at Naples	75	0	0
Luminous Meteors	30	0	0
Elasticity of Wires	100	0	0
Dipterocarpæ, Report on......	20	0	0
Mechanical Equivalent of Heat............................	35	0	0
Double Compounds of Cobalt and Nickel	8	0	0
Underground Temperatures	50	0	0
Settle Cave Exploration	100	0	0
Underground Waters in New Red Sandstone	10	0	0
Action of Ethyl Bromobutyrate on Ethyl Sodacetoacetate	10	0	0
British Earthworks	25	0	0
Atmospheric Elasticity in India	15	0	0
Development of Light from Coal-gas	20	0	0
Estimation of Potash and Phosphoric Acid...............	1	18	0
Geological Record..............	100	0	0
Anthropometric Committee	34	0	0
Physiological Action of Phosphoric Acid, &c...............	15	0	0
	£1128	9	7

1878.

	£	s.	d.
Exploration of Settle Caves	100	0	0
Geological Record..............	100	0	0
Investigation of Pulse Phenomena by means of Syphon Recorder	10	0	0
Zoological Station at Naples	75	0	0
Investigation of Underground Waters..........................	15	0	0
Transmission of Electrical Impulses through Nerve Structure.......................	30	0	0
Calculation of Factor Table of Fourth Million	100	0	0
Anthropometric Committee...	66	0	0
Chemical Composition and Structure of less known Alkaloids..........................	25	0	0
Exploration of Kent's Cavern	50	0	0
Zoological Record	100	0	0
Fermanagh Caves Exploration	15	0	0
Thermal Conductivity of Rocks	4	16	6
Luminous Meteors...............	10	0	0
Ancient Earthworks	25	0	0
	£725	16	6

1879.

	£	s.	d.
Table at the Zoological Station, Naples	75	0	0
Miocene Flora of the Basalt of the North of Ireland ...	20	0	0
Illustrations for a Monograph on the Mammoth	17	0	0
Record of Zoological Literature	100	0	0
Composition and Structure of less-known Alkaloids	25	0	0

	£	s.	d.
Exploration of Caves in Borneo	50	0	0
Kent's Cavern Exploration	100	0	0
Record of the Progress of Geology	100	0	0
Fermanagh Caves Exploration	5	0	0
Electrolysis of Metallic Solutions and Solutions of Compound Salts	25	0	0
Anthropometric Committee	50	0	0
Natural History of Socotra	100	0	0
Calculation of Factor Tables for 5th and 6th Millions	150	0	0
Circulation of Underground Waters	10	0	0
Steering of Screw Steamers	10	0	0
Improvements in Astronomical Clocks	30	0	0
Marine Zoology of South Devon	20	0	0
Determination of Mechanical Equivalent of Heat	12	15	6
Specific Inductive Capacity of Sprengel Vacuum	40	0	0
Tables of Sun-heat Coefficients	30	0	0
Datum Level of the Ordnance Survey	10	0	0
Tables of Fundamental Invariants of Algebraic Forms	36	14	9
Atmospheric Electricity Observations in Madeira	15	0	0
Instrument for Detecting Fire-damp in Mines	22	0	0
Instruments for Measuring the Speed of Ships	17	1	8
Tidal Observations in the English Channel	10	0	0
	£1080	11	11

1880.

	£	s.	d.
New Form of High Insulation Key	10	0	0
Underground Temperature	10	0	0
Determination of the Mechanical Equivalent of Heat	8	5	0
Elasticity of Wires	50	0	0
Luminous Meteors	30	0	0
Lunar Disturbance of Gravity	30	0	0
Fundamental Invariants	8	5	0
Laws of Water Friction	20	0	0
Specific Inductive Capacity of Sprengel Vacuum	20	0	0
Completion of Tables of Sun-heat Coefficients	50	0	0
Instrument for Detection of Fire-damp in Mines	10	0	0
Inductive Capacity of Crystals and Paraffines	4	17	7
Report on Carboniferous Polyzoa	10	0	0
Caves of South Ireland	10	0	0
Viviparous Nature of Ichthyosaurus	10	0	0
Kent's Cavern Exploration	50	0	0
Geological Record	100	0	0
Miocene Flora of the Basalt of North Ireland	15	0	0
Underground Waters of Permian Formations	5	0	0
Record of Zoological Literature	100	0	0
Table at Zoological Station at Naples	75	0	0
Investigation of the Geology and Zoology of Mexico	50	0	0
Anthropometry	50	0	0
Patent Laws	5	0	0
	£731	7	7

1881.

	£	s.	d.
Lunar Disturbance of Gravity	30	0	0
Underground Temperature	20	0	0
High Insulation Key	5	0	0
Tidal Observations	10	0	0
Fossil Polyzoa	10	0	0
Underground Waters	10	0	0
Earthquakes in Japan	25	0	0
Tertiary Flora	20	0	0
Scottish Zoological Station	50	0	0
Naples Zoological Station	75	0	0
Natural History of Socotra	50	0	0
Zoological Record	100	0	0
Weights and Heights of Human Beings	30	0	0
Electrical Standards	25	0	0
Anthropological Notes and Queries	9	0	0
Specific Refractions	7	3	1
	£476	3	1

1882.

	£	s.	d.
Tertiary Flora of North of Ireland	20	0	0
Exploration of Caves of South of Ireland	10	0	0
Fossil Plants of Halifax	15	0	0
Fundamental Invariants of Algebraical Forms	76	1	11
Record of Zoological Literature	100	0	0
British Polyzoa	10	0	0
Naples Zoological Station	80	0	0
Natural History of Timor-laut	100	0	0
Conversion of Sedimentary Materials into Metamorphic Rocks	10	0	0
Natural History of Socotra	100	0	0
Circulation of Underground Waters	15	0	0
Migration of Birds	15	0	0
Earthquake Phenomena of Japan	25	0	0

	£	s.	d.
Geological Map of Europe ...	25	0	0
Elimination of Nitrogen by Bodily Exercise	50	0	0
Anthropometric Committee...	50	0	0
Photographing Ultra-Violet Spark Spectra	25	0	0
Exploration of Raygill Fissure	20	0	0
Calibration of Mercurial Thermometers	20	0	0
Wave-length Tables of Spectra of Elements	50	0	0
Geological Record	100	0	0
Standards for Electrical Measurements	100	0	0
Exploration of Central Africa	100	0	0
Albuminoid Substances of Serum	10	0	0
	£1126	1	11

1883.

	£	s.	d.
Natural History of Timor-laut	50	0	0
British Fossil Polyzoa	10	0	0
Circulation of Underground Waters	15	0	0
Zoological Literature Record	100	0	0
Exploration of Mount Kilima-njaro	500	0	0
Erosion of Sea-coast of England and Wales	10	0	0
Fossil Plants of Halifax	20	0	0
Elimination of Nitrogen by Bodily Exercise	38	3	3
Isomeric Naphthalene Derivatives	15	0	0
Zoological Station at Naples	80	0	0
Investigation of Loughton Camp	10	0	0
Earthquake Phenomena of Japan	50	0	0
Meteorological Observations on Ben Nevis	50	0	0
Fossil Phyllopoda of Palæozoic Rocks	25	0	0
Migration of Birds	20	0	0
Geological Record	50	0	0
Exploration of Caves in South of Ireland	10	0	0
Scottish Zoological Station...	25	0	0
Screw Gauges	5	0	0
	£1083	3	3

1884.

	£	s.	d.
Zoological Literature Record	100	0	0
Fossil Polyzoa	10	0	0
Exploration of Mount Kilima-njaro, East Africa	500	0	0
Anthropometric Committee...	10	0	0
Fossil Plants of Halifax	15	0	0
International Geological Map	20	0	0
Erratic Blocks of England ...	10	0	0
Natural History of Timor-laut	50	0	0
Coagulation of Blood	100	0	0
Naples Zoological Station ...	80	0	0
Bibliography of Groups of Invertebrata	50	0	0
Earthquake Phenomena of Japan	75	0	0
Fossil Phyllopoda of Palæozoic Rocks	15	0	0
Meteorological Observatory at Chepstow	25	0	0
Migration of Birds	20	0	0
Collecting and Investigating Meteoric Dust	20	0	0
Circulation of Underground Waters	5	0	0
Ultra-Violet Spark Spectra ...	8	4	0
Tidal Observations	10	0	0
Meteorological Observations on Ben Nevis	50	0	0
	£1173	4	0

1885.

	£	s.	d.
Zoological Literature Record.	100	0	0
Vapour Pressures, &c., of Salt Solutions	25	0	0
Physical Constants of Solutions	20	0	0
Recent Polyzoa	10	0	0
Naples Zoological Station ...	100	0	0
Exploration of Mount Kilima-njaro	25	0	0
Fossil Plants of British Tertiary and Secondary Beds .	50	0	0
Calculating Tables in Theory of Numbers	100	0	0
Exploration of New Guinea...	200	0	0
Exploration of Mount Roraima	100	0	0
Meteorological Observations on Ben Nevis	50	0	0
Volcanic Phenomena of Vesuvius	25	0	0
Biological Stations on Coasts of United Kingdom	150	0	0
Meteoric Dust	70	0	0
Marine Biological Station at Granton	100	0	0
Fossil Phyllopoda of Palæozoic Rocks	25	0	0
Migration of Birds	30	0	0
Synoptic Chart of Indian Ocean	50	0	0
Circulation of Underground Waters	10	0	0
Geological Record	50	0	0
Reduction of Tidal Observations	10	0	0
Earthquake Phenomena of Japan	70	0	0
Raygill Fissure	15	0	0
	£1385	0	0

General Meetings.

On Wednesday, September 9, at 8 P.M., in the Music Hall, the Right Hon. Lord Rayleigh, M.A., D.C.L., LL.D., F.R.S., F.R.A.S., F.R.G.S., resigned the office of President to the Right Hon. Sir Lyon Playfair, K.C.B., M.P., Ph.D., LL.D., F.R.S. L. & E., F.C.S., who took the Chair, and delivered an Address, for which see page 1.

On Thursday, September 10, at 8 P.M., a Soirée took place in the Art Gallery.

On Friday, September 11, at 8 P.M., in the Music Hall, Professor W. G. Adams, M.A., F.R.S., F.G.S., delivered a Discourse on 'The Electric Light and Atmospheric Absorption.'

On Monday, September 14, at 8.30 P.M., in the Music Hall, Mr. John Murray, F.R.S.E., delivered a Discourse on 'The Great Ocean Basins.'

On Tuesday, September 15, at 8 P.M., a Soirée took place in the Art Gallery.

On Wednesday, September 16, at 2.30 P.M., the concluding General Meeting took place in St. Katherine's Hall, when the Proceedings of the General Committee and the Grants of Money for Scientific purposes were explained to the Members.

The Meeting was then adjourned to Birmingham. [The Meeting is appointed to commence on Wednesday, September 1, 1886.]

PRESIDENT'S ADDRESS.

ADDRESS

BY

THE RIGHT HON. SIR LYON PLAYFAIR,

K.C.B., M.P., F.R.S.

PRESIDENT.

I. *Visit to Canada.*

Our meeting at Montreal was a notable event in the life of the British Association, and even marked a distinct epoch in the history of civilisation. It was by no mere accident that the constitution of the Association enabled it to embrace all parts of the British Empire. Science is truly catholic, and is bounded only by the universe. In relation to our vast empire, science, as well as literature and art, is the common possession of all its varying people. The United Kingdom is limited to 120,800 square miles, inhabited by 35 millions of people; but the empire as a whole has $8\frac{1}{2}$ millions of square miles, with a population of 305 millions. To federate such vast possessions and so teeming a population into a political unit is a work only to be accomplished by the labours and persistent efforts of perhaps several generations of statesmen. The federation of its science is a subject of less dimensions well within the range of experiment. No part of the British Empire was more suited than Canada to try whether her science could be federated with our science. Canada has lately federated distinct provinces, with conflicting interests arising from difference of races, nationalities, and religions. Political federation is not new in the history of the world, though it generally arises as a consequence of war. It was war that taught the Netherlands to federate in 1619. It was war which united the States in America; federated Switzerland, Germany, and Austria, and unified Italy. But Canada formed a great national life out of petty provincial existences in a time of profound peace. This evolution gave an immense impulse to her national resources. The Dominion still requires consolidation in its vast extent, and applied science is rapidly effecting it. Canada, with its great expanse of territory, nearly as large as the United States, is being knit

together by the iron bands of railways from the Gulf of St. Lawrence to the Pacific Ocean, so that the fertile lands of Ontario, Manitoba, Columbia, and the North-Western Territories will soon be available to the world. Still practical science has much to accomplish. England and France, with only one-fifth the fertile area of Canada, support 80 millions of people, while Canada has a population not exceeding 5 millions.

A less far-seeing people than the Canadians might have invited the applied science which they so much require. But they knew that without science there are no applications. They no doubt felt with Emerson—

> And what if Trade sow cities
> Like shells along the shore,
> And thatch with towns the prairie broad
> With railways ironed o'er;
> They are but sailing foam-bells
> Along Thought's causing stream,
> And take their shape and sun-colour
> From him that sends the dream.

So it was with a far-reaching foresight that the Canadian Government invited the British Association for the Advancement of Science to meet in Montreal. The inhabitants of Canada received us with open arms, and the science of the Dominion and that of the United Kingdom were welded. We found in Canada, as we had every reason to expect, men of manly and self-reliant character who loved not less than we did the old home from which they had come. Among them is the same healthiness of political and moral life, with the same love of truth which distinguishes the English people. Our great men are their great men; our Shakspeare, Milton, and Burns belong to them as much as to ourselves; our Newton, Dalton, Faraday, and Darwin are their men of science as much as they are ours. Thus a common possession and mutual sympathy made the meeting in Canada a successful effort to stimulate the progress of science, while it established, at the same time, the principle that all people of British origin—and I would fain include our cousins in the United States—possess a common interest in the intellectual glories of their race, and ought, in science at least, to constitute part and parcel of a common empire, whose heart may beat in the small islands of the Northern seas, but whose blood circulates in all her limbs, carrying warmth to them and bringing back vigour to us. Nothing can be more cheering to our Association than to know that many of the young communities of English-speaking people all over the globe—in India, China, Japan, the Straits, Ceylon, Australia, New Zealand, the Cape—have founded scientific societies in order to promote the growth of scientific research. No doubt science, which is only a form of truth, is one in all lands, but still its unity of purpose and fulfilment received an important practical expression by our visit to Canada. This community of science will be continued by the fact that we have invited Sir William Dawson, of Montreal, to be our next President at Birmingham.

II. *Science and the State.*

I cannot address you in Aberdeen without recollecting that when we last met in this city our President was a great prince. The just verdict of time is that, high as was his royal rank, he has a far nobler claim to our regard as a lover of humanity in its widest sense, and especially as a lover of those arts and sciences which do so much to adorn it. On September 14, 1859, I sat on this platform and listened to the eloquent address and wise counsel of the Prince Consort. At one time a member of his household, it was my privilege to co-operate with this illustrious prince in many questions relating to the advancement of science. I naturally, therefore, turned to his presidential address to see whether I might not now continue those counsels which he then gave with all the breadth and comprehensiveness of his masterly speeches. I found, as I expected, a text for my own discourse in some pregnant remarks which he made upon the relation of Science to the State. They are as follows:—'We may be justified in hoping . . . that the Legislature and the State will more and more recognise the claims of science to their attention, so that it may no longer require the begging-box, but speak to the State like a favoured child to its parent, sure of his paternal solicitude for its welfare; that the State will recognise in science one of its elements of strength and prosperity, to foster which the clearest dictates of self-interest demand.'

This opinion, in its broadest sense, means that the relations of science to the State should be made more intimate because the advance of science is needful to the public weal.

The importance of promoting science as a duty of statecraft was well enough known to the ancients, especially to the Greeks and Arabs, but it ceased to be recognised in the dark ages, and was lost to sight during the revival of letters in the fifteenth and sixteenth centuries. Germany and France, which are now in such active competition in promoting science, have only publicly acknowledged its national importance in recent times. Even in the last century, though France had its Lavoisier and Germany its Leibnitz, their Governments did not know the value of science. When the former was condemned to death in the Reign of Terror, a petition was presented to the rulers that his life might be spared for a few weeks in order that he might complete some important experiments, but the reply was, 'The Republic has no need of savants.' Earlier in the century the much-praised Frederick William of Prussia shouted with a loud voice, during a graduation ceremony in the University of Frankfort, 'An ounce of mother-wit is worth a ton of university wisdom.' Both France and Germany are now ashamed of these utterances of their rulers, and make energetic efforts to advance science with the aid of their national resources. More remarkable is it to see a young nation like the United States reserving large tracts of its national lands for the promotion of scientific education. In some respects this young country is in advance of all

together by the iron bands of railways from the Gulf of St. Lawrence to the Pacific Ocean, so that the fertile lands of Ontario, Manitoba, Columbia, and the North-Western Territories will soon be available to the world. Still practical science has much to accomplish. England and France, with only one-fifth the fertile area of Canada, support 80 millions of people, while Canada has a population not exceeding 5 millions.

A less far-seeing people than the Canadians might have invited the applied science which they so much require. But they knew that without science there are no applications. They no doubt felt with Emerson—

> And what if Trade sow cities
> Like shells along the shore,
> And thatch with towns the prairie broad
> With railways ironed o'er;
> They are but sailing foam-bells
> Along Thought's causing stream,
> And take their shape and sun-colour
> From him that sends the dream.

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European nations in joining science to its administrative offices. Its scientific publications, like the great palæontological work embodying the researches of Professor Marsh and his associates in the Geological Survey, are an example to other Governments. The Minister of Agriculture is surrounded with a staff of botanists and chemists. The Home Secretary is aided by a special Scientific Commission to investigate the habits, migrations, and food of fishes, and the latter has at its disposal two specially-constructed steamers of large tonnage. The United States and Great Britain promote fisheries on distinct systems. In this country we are perpetually issuing expensive Commissions to visit the coasts in order to ascertain the experiences of fishermen. I have acted as Chairman of one of these Royal Commissions, and found that the fishermen, having only a knowledge of a small area, gave the most contradictory and unsatisfactory evidence. In America the questions are put to Nature, and not to fishermen. Exact and searching investigations are made into the life-history of the fishes, into the temperature of the sea in which they live and spawn, into the nature of their food, and into the habits of their natural enemies. For this purpose the Government give the co-operation of the navy, and provide the Commission with a special corps of skilled naturalists, some of whom go out with the steamships and others work in the biological laboratories at Wood's Holl, Massachusetts, or at Washington. The different universities send their best naturalists to aid in these investigations, which are under the direction of Mr. Baird, of the Smithsonian Institution. The annual cost of the Federal Commission is about 40,000*l.*, while the separate States spend about 20,000*l.* in local efforts. The practical results flowing from these scientific investigations have been important. The inland waters and rivers have been stocked with fish of the best and most suitable kinds. Even the great ocean which washes the coasts of the United States is beginning to be affected by the knowledge thus acquired, and a sensible result is already produced upon the most important of its fisheries. The United Kingdom largely depends upon its fisheries, but as yet our Government have scarcely realised the value of such scientific investigations as those pursued with success by the United States. Less systematically, but with great benefit to science, our own Government has used the surveying expeditions, and sometimes has equipped special expeditions to promote natural history and solar physics. Some of the latter, like the voyage of the 'Challenger,' have added largely to the store of knowledge; while the former, though not primarily intended for scientific research, have had an indirect result of infinite value by becoming training-schools for such investigators as Edward Forbes, Darwin, Hooker, Huxley, Wyville Thomson, and others.

In the United Kingdom we are just beginning to understand the wisdom of Washington's farewell address to his countrymen, when he said: 'Promote as an object of primary importance institutions for the general diffusion of knowledge. In proportion as the structure of a government

gives force to public opinion, it is essential that public opinion should be enlightened.' It was only in 1870 that our Parliament established a system of national primary education. Secondary education is chaotic, and remains unconnected with the State, while the higher education of the universities is only brought at distant intervals under the view of the State. All great countries except England have Ministers of Education, but this country has only Ministers who are the managers of primary schools. We are inferior even to smaller countries in the absence of organised State supervision of education. Greece, Portugal, Egypt, and Japan have distinct Ministers of Education, and so also among our Colonies have Victoria and New Zealand. Gradually England is gathering materials for the establishment of an efficient Education Minister. The Department of Science and Art is doing excellent work in diffusing a taste for elementary science among the working classes. There are now about 78,000 persons who annually come under the influence of its science classes, while a small number of about two hundred, many of them teachers, receive thorough instruction in science at the excellent school in South Kensington of which Professor Huxley is the Dean. I do not dwell on the work of this Government department, because my object is chiefly to point out how it is that science lags in its progress in the United Kingdom owing to the deficient interest taken in it by the middle and upper classes. The working classes are being roused from their indifference. They show this by their selection of scientific men as candidates at the next election. Among these are Professors Stuart, Roscoe, Maskelyne, and Rücker. It has its significance that such a humble representative of science as myself received invitations from working-class constituencies in more than a dozen of the leading manufacturing towns. In the next Parliament I do not doubt that a Minister of Education will be created as a nucleus round which the various educational materials may crystallise in a definite form.

III. *Science and Secondary Education.*

Various Royal Commissions have made inquiries and issued recommendations in regard to our public and endowed schools. The Commissions of 1861, 1864, 1868, and 1873 have expressed the strongest disapproval of the condition of our schools, and, so far as science is concerned, their state is much the same as when the Duke of Devonshire's Commission in 1873 reported in the following words:—'Considering the increasing importance of science to the material interests of the country, we cannot but regard its almost total exclusion from the training of the upper and middle classes as little less than a national misfortune.' No doubt there are exceptional cases and some brilliant examples of improvement since these words were written, but generally throughout the country teaching in science is a name rather than a reality. The Technical Commission which reported last year can only point to three schools in Great Britain in which science is fully and adequately taught.

While the Commission gives us the consolation that England is still in advance as an industrial nation, it warns us that foreign nations, which were not long ago far behind, are now making more rapid progress than this country, and will soon pass it in the race of competition unless we give increased attention to science in public education. A few of the large towns, notably Manchester, Bradford, Huddersfield, and Birmingham, are doing so. The working classes are now receiving better instruction in science than the middle classes. The competition of actual life asserts its own conditions, for the children of the latter find increasing difficulty in obtaining employment. The cause of this lies in the fact that the schools for the middle classes have not yet adapted themselves to the needs of modern life. It is true that many of the endowed schools have been put under new schemes, but as there is no public supervision or inspection of them, we have no knowledge as to whether they have prospered or slipped back. Many corporate schools have arisen, some of them, like Clifton, Cheltenham, and Marlborough Colleges, doing excellent educational work, though as regards all of them the public have no rights and cannot enforce guarantees for efficiency. A Return just issued, on the motion of Sir John Lubbock, shows a lamentable deficiency in science teaching in a great proportion of the endowed schools. While twelve to sixteen hours per week are devoted to classics, two to three hours are considered ample for science in a large proportion of the schools. In Scotland there are only six schools in the Return which give more than two hours to science weekly, while in many schools its teaching is wholly omitted. Every other part of the kingdom stands in a better position than Scotland in relation to the science of its endowed schools. The old traditions of education stick as firmly to schools as a limpet does to a rock; though I do the limpet injustice, for it does make excursions to seek pastures new. Are we to give up in despair because an exclusive system of classical education has resisted the assaults of such cultivated authors as Milton, Montaigne, Cowley, and Locke? There was once an enlightened Emperor of China, Chi Hwangti, who knew that his country was kept back by its exclusive devotion to the classics of Confucius and Mencius. He invited 500 of the teachers to bring their copies of these authors to Pekin, and after giving a great banquet in their honour, he buried alive the professors along with their manuscripts in a deep pit. But Confucius and Mencius still reign supreme. I advocate milder measures, and depend for their adoption on the force of public opinion. The needs of modern life will force schools to adapt themselves to a scientific age. Grammar-schools believe themselves to be immortal. Those curious immortals—the Struldbrugs—described by Swift, ultimately regretted their immortality, because they found themselves out of touch, sympathy, and fitness with the centuries in which they lived.

As there is no use clamouring for an instrument of more compass and power until we have made up our mind as to the tune, Professor Huxley, in

his evidence before a Parliamentary Committee in 1884, has given a time-table for grammar-schools. He demands that out of their forty hours for public and private study, ten should be given to modern languages and history, eight to arithmetic and mathematics, six to science, and two to geography, thus leaving fourteen hours to the dead languages. No time-table would, however, be suitable to all schools. The great public schools of England will continue to be the gymnasia for the upper classes, and should devote much of their time to classical and literary culture. Even now they introduce into their curriculum subjects unknown to them when the Royal Commission of 1868 reported, though they still accept science with timidity. Unfortunately, the other grammar-schools which educate the middle classes look to the higher public schools as a type to which they should conform, although their functions are so different. It is in the interest of the higher public schools that this difference should be recognised, so that, while they give an all-round education and expand their curriculum by a freer recognition of the value of science as an educational power in developing the faculties of the upper classes, the schools for the middle classes should adapt themselves to the needs of their existence, and not keep up a slavish imitation of schools with a different function.

The stock argument against the introduction of modern subjects into grammar-schools is that it is better to teach Latin and Greek thoroughly rather than various subjects less completely. But is it true that thoroughness in teaching dead languages is the result of an exclusive system? In 1868 the Royal Commission stated that even in the few great public schools thoroughness was only given to thirty per cent. of the scholars, at the sacrifice of seventy per cent. who got little benefit from the system. Since then the curriculum has been widened and the teaching has improved. I question the soundness of the principle that it is better to limit the attention of the pupils mainly to Latin and Greek, highly as I value their educational power to a certain order of minds. As in biology the bodily development of animals is from the general to the special, so is it in the mental development of man. In the school a boy should be aided to discover the class of knowledge that is best suited for his mental capacities, so that, in the upper forms of the school and in the university, knowledge may be specialised in order to cultivate the powers of the man to their fullest extent. Shakspeare's educational formula may not be altogether true, but it contains a broad basis of truth—

> No profit grows, where is no pleasure ta'en;—
> In brief, sir, study what you most affect.

The comparative failure of the modern side of school education arises from constituting it out of the boys who are looked upon as classical asses. Milton pointed out that in all schools there are boys to whom the dead languages are 'like thorns and thistles,' which form a poor nourishment even for asses. If teachers looked upon these classical asses as beings who might receive mental nurture according to their nature,

much higher results would follow the bifurcation of our schools. Saul went out to look for asses and he found a kingdom. Surely this fact is more encouraging than the example of Gideon, who 'took thorns of the wilderness and briars, and with these he *taught* the men of Succoth.'[1] The adaptation of public schools to a scientific age does not involve a contest as to whether science or classics shall prevail, for both are indispensable to true education. The real question is whether schools will undertake the duty of moulding the minds of boys according to their mental varieties. Classics, from their structural perfection and power of awakening dormant faculties, have claims to precedence in education, but they have none to a practical monopoly. It is by claiming the latter that teachers sacrifice mental receptivity to a Procrustean uniformity.

The universities are changing their traditions more rapidly than the schools. The *via antiqua* which leads to them is still broad, though a *via moderna*, with branching avenues, is also open to their honours and emoluments. Physical science, which was once neglected, is now encouraged at the universities. As to the seventy per cent. of boys who leave schools for life-work without going through the universities, are there no growing signs of discontent which must force a change? The Civil Service, the learned professions, as well as the army and navy, are now barred by examinations. Do the boys of our public schools easily leap over the bars, although some of them have lately been lowered so as to suit the schools? So difficult are these bars to scholars that crammers take them in hand before they attempt the leap; and this occurs in spite of the large value attached to the dead languages and the small value placed on modern subjects. Thus, in the Indian Civil Service examinations, 800 marks as a maximum are assigned to Latin, 600 to Greek, 500 to chemistry, and 300 to each of the other physical sciences. But if we take the average working of the system for the last four years, we find that while sixty-eight per cent. of the maximum were given to candidates in Greek and Latin, only forty-five per cent. were accorded to candidates in chemistry, and but thirty per cent. to the other physical sciences. Schools sending up boys for competition naturally shun subjects which are dealt with so hardly and so heavily handicapped by the State.

Passing from learned or public professions to commerce, how is it that in our great commercial centres, foreigners—German, Swiss, Dutch, and even Greeks—push aside our English youth and take the places of profit which belong to them by national inheritance? How is it that in our Colonies, like those in South Africa, German enterprise is pushing aside English incapacity? How is it that we find whole branches of manufactures, when they depend on scientific knowledge, passing away from this country, in which they originated, in order to engraft themselves abroad, although their decaying roots remain at home?[2] The answer to

[1] Judges viii. 16.

[2] See Dr. Perkins' address to the Soc. Chem. Industry. 'Nature,' Aug. 6, 1885, p. 333.

these questions is that our systems of education are still too narrow for the increasing struggle of life.

Faraday, who had no narrow views in regard to education, deplored the future of our youth in the competition of the world, because, as he said with sadness, 'our schoolboys, when they come out of school, are ignorant of their ignorance at the end of all that education.'

The opponents of science education allege that it is not adapted for mental development, because scientific facts are often disjointed and exercise only the memory. Those who argue thus do not know what science is. No doubt an ignorant or half-informed teacher may present science as an accumulation of unconnected facts. At all times and in all subjects there are teachers without æsthetical or philosophical capacity—men who can only see carbonate of lime in a statue by Phidias or Praxiteles; who cannot survey zoology on account of its millions of species, or botany because of its 130,000 distinct plants; men who can look at trees without getting a conception of a forest, and cannot distinguish a stately edifice from its bricks. To teach in that fashion is like going to the tree of science with its glorious fruit in order to pick up a handful of the dry fallen leaves from the ground. It is, however, true that as science teaching has had less lengthened experience than that of literature, its methods of instruction are not so matured. Scientific and literary teaching have different methods; for while the teacher of literature rests on authority and on books for his guidance, the teacher of science discards authority and depends on facts at first hand, and on the book of Nature for their interpretation. Natural science more and more resolves itself into the teaching of the laboratory. In this way it can be used as a powerful means of quickening observation, and of creating a faculty of induction after the manner of Zadig, the Babylonian described by Voltaire. Thus facts become surrounded by scientific conceptions, and are subordinated to order and law.

It is not those who desire to unite literature with science who degrade education; the degradation is the consequence of the refusal. A violent reaction—too violent to be wise—has lately taken place against classical education in France, where their own vernacular occupies the position of dead languages, while Latin and science are given the same time in the curriculum. In England manufacturers cry out for technical education, in which classical culture shall be excluded. In the schools of the middle classes science rather than technics is needed, because, when the seeds of science are sown, technics as its fruit will appear at the appointed time. Epictetus was wise when he told us to observe that, though sheep eat grass, it is not grass but wool that grows on their backs. Should, however, our grammar-schools persist in their refusal to adapt themselves to the needs of a scientific age, England must follow the example of other European nations and found new modern schools in competition with them. For, as Huxley has put it, we cannot continue in this age 'of full modern artillery to turn out our boys to do battle in it, equipped only

with the sword and shield of an ancient gladiator.' In a scientific and keenly competitive age an exclusive education in the dead languages is a perplexing anomaly. The flowers of literature should be cultivated and gathered, though it is not wise to send men into our fields of industry to gather the harvest when they have been taught only to cull the poppies and to push aside the wheat.

IV. *Science and the Universities.*

The State has always felt bound to alter and improve universities, even when their endowments are so large as to render it unnecessary to support them by public funds. When universities are poor, Parliament gives aid to them from imperial taxation. In this country that aid has been given with a very sparing hand. Thus the universities and colleges of Ireland have received about thirty thousand pounds annually, and the same sum has been granted to the four universities of Scotland. Compared with imperial aid to foreign universities such sums are small. A single German university like Strasburg or Leipsic receives above 40,000*l.* annually, or 10,000*l.* more than the whole colleges of Ireland or of Scotland. Strasburg, for instance, has had her university and its library rebuilt at a cost of 711,000*l.*, and receives an annual subscription of 43,000*l.* In rebuilding the university of Strasburg eight laboratories have been provided, so as to equip it fully with the modern requirements for teaching and research.[1] Prussia, the most economical nation in the world, spends 391,000*l.* yearly out of taxation on her universities.

The recent action of France is still more remarkable. After the Franco-German War the Institute of France discussed the important question:—'Pourquoi la France n'a pas trouvé d'hommes supérieurs au moment du péril?' The general answer was because France had allowed university education to sink to a low ebb. Before the great Revolution France had twenty-three autonomous universities in the provinces. Napoleon desired to found one great university at Paris, and he crushed out the others with the hand of a despot, and remodelled the last with the instincts of a drill-sergeant. The central university sank so low that in 1868 it is said that only 8,000*l.* were spent for true academic purposes. Startled by the intellectual sterility shown in the war, France has made gigantic efforts to retrieve her position, and has rebuilt the provincial colleges at a cost of 3,280,000*l.*, while her annual budget for their support now reaches half a million of pounds. In order to open these provincial colleges to the best talent of France, more than five hundred scholarships have been founded at an annual cost of 30,000*l.* France now recognises that it is not by the number of men under arms that she can compete with her great neighbour Germany, so she has determined to equal her in intellect.

[1] The cost of these laboratories has been as follows:—Chemical Institute, 35,000*l.*; Physical Institute, 28,000*l.*; Botanical Institute, 26,000*l.*; Observatory, 25,000*l.*; Anatomy, 42,000*l.*; Clinical Surgery, 26,000*l.*; Physiological Chemistry, 16,000*l.*; Physiological Institute, 13,900*l.*

You will understand why it is that Germany was obliged, even if she had not been willing, to spend such large sums in order to equip the university of her conquered province, Alsace-Lorraine. France and Germany are fully aware that science is the source of wealth and power, and that the only way of advancing it is to encourage universities to make researches and to spread existing knowledge through the community. Other European nations are advancing on the same lines. Switzerland is a remarkable illustration of how a country can compensate itself for its natural disadvantages by a scientific education of its people. Switzerland contains neither coal nor the ordinary raw materials of industry, and is separated from other countries which might supply them by mountain barriers. Yet, by a singularly good system of graded schools, and by the great technical college of Zürich, she has become a prosperous manufacturing country. In Great Britain we have nothing comparable to this technical college, either in magnitude or efficiency. Belgium is reorganising its universities, and the State has freed the localities from the charge of buildings, and will in future equip the universities with efficient teaching resources out of public taxation. Holland, with a population of 4,000,000 and a small revenue of 9,000,000*l.*, spends 136,000*l.* on her four universities. Contrast this liberality of foreign countries in the promotion of higher instruction with the action of our own country. Scotland, like Holland, has four universities, and is not very different from it in population, but it only receives 30,000*l.* from the State. By a special clause in the Scotch Universities Bill the Government asked Parliament to declare that under no circumstances should the Parliamentary grant be ever increased above 40,000*l.* According to the views of the British Treasury there is a finality in science and in expanding knowledge.

The wealthy universities of Oxford and Cambridge are gradually constructing laboratories for science. The merchant princes of Manchester have equipped their new Victoria University with similar laboratories. Edinburgh and Glasgow Universities have also done so, partly at the cost of Government and largely by private subscriptions. The poorer universities of Aberdeen and St. Andrews are still inefficiently provided with the modern appliances for teaching science.

London has one small Government college and two chartered colleges, but is wholly destitute of a teaching university. It would excite great astonishment at the Treasury if we were to make the modest request that the great metropolis, with a population of four millions, should be put into as efficient academical position as the town of Strasburg, with 104,000 inhabitants, by receiving, as that town does, 43,000*l.* annually for academic instruction, and 700,000*l.* for university buildings. Still, the amazing anomaly that London has no teaching university must ere long cease.

It is a comforting fact that, in spite of the indifference of Parliament, the large towns of the kingdom are showing their sense of the need of

higher education. Manchester has already its university. Nottingham, Birmingham, Leeds, and Bristol have colleges more or less complete. Liverpool converts a disused lunatic asylum into a college for sane people. Cardiff rents an infirmary for a collegiate building. Dundee, by private benefaction, rears a Baxter College with larger ambitions. All these are healthy signs that the public are determined to have advanced science teaching; but the resources of the institutions are altogether inadequate to the end in view. Even in the few cases where the laboratories are efficient for teaching purposes, they are inefficient as laboratories for research. Under these circumstances the Royal Commission on Science advocates special Government laboratories for research. Such laboratories, supported by public money, are as legitimate subjects for expenditure as galleries for pictures or sculpture; but I think that they would not be successful, and would injure science if they failed. It would be safer in the meantime if the State assisted universities or well-established colleges to found laboratories of research under their own care. Even such a proposal shocks our Chancellor of the Exchequer, who tells us that this country is burdened with public debt, and has ironclads to build and arsenals to provide. Nevertheless our wealth is proportionally much greater than that of foreign States which are competing with so much vigour in the promotion of higher education. They deem such expenditure to be true economy, and do not allow their huge standing armies to be an apology for keeping their people backwards in the march of knowledge. France, which in the last ten years has been spending a million annually on university education, had a war indemnity to pay, and competes successfully with this country in ironclads. Either all foreign States are strangely deceived in their belief that the competition of the world has become a competition of intellect, or we are marvellously unobservant of the change which is passing over Europe in the higher education of the people. Preparations for war will not ensure to us the blessings and security of an enlightened peace. Protective expenditure may be wise, though productive expenditure is wiser.

> Were half the powers which fill the world with terror,
> Were half the wealth bestowed on camps and courts,
> Given to redeem the human mind from error—
> There were no need of arsenals and forts.

Universities are not mere storehouses of knowledge; they are also conservatories for its cultivation. In Mexico there is a species of ant which sets apart some of its individuals to act as honey-jars by monstrously extending their abdomens to store the precious fluid till it is wanted by the community. Professors in a university have a higher function, because they ought to make new honey as well as to store it. The widening of the bounds of knowledge, literary or scientific, is the crowning glory of university life. Germany unites the functions of teaching and research in the universities, while France keeps them in separate institutions. The former system is best adapted to our habits, but its

condition for success is that our science chairs should be greatly increased, so that teachers should not be wholly absorbed in the duties of instruction. Germany subdivides the sciences into various chairs, and gives to the professors special laboratories. It also makes it a condition for the higher honours of a university that the candidates shall give proofs of their ability to make original researches. Under such a system, teaching and investigation are not incompatible. In the evidence before the Science Commission many opinions were given that scientific men engaged in research should not be burdened with the duties of education, and there is much to be said in support of this view when a single professor for the whole range of a physical science is its only representative in a university. But I hope that such a system will not long continue, for if it do we must occupy a very inferior position as a nation in the intellectual competition of Europe. Research and education in limited branches of higher knowledge are not incompatible. It is true that Galileo complained of the burden imposed upon him by his numerous astronomical pupils, though few other philosophers have echoed this complaint. Newton, who produced order in worlds, and Dalton, who brought atoms under the reign of order and number, rejoiced in their pupils. Lalande spread astronomers as Liebig spread chemists, and Johannes Müller biologists, all over the world. Laplace, La Grange, Dulong, Gay Lussac, Berthollet, and Dumas were professors as well as discoverers in France. In England our discoverers have generally been teachers. In fact I recollect only three notable examples of men who were not—Boyle, Cavendish, and Joule. It was so in ancient as well as in modern times, for Plato and Aristotle taught and philosophised. If you do not make the investigator a schoolmaster, as Dalton was, and as practically our professors are at the present time, with the duty of teaching all branches of their sciences, the mere elementary truths as well as the highest generalisations being compressed into a course, it is well that they should be brought into contact with the world in which they live, so as to know its wants and aspirations. They could then quicken the pregnant minds around them, and extend to others their own power and love of research. Goethe had a fine perception of this when he wrote—

> Wer in der Weltgeschichte lebt,
> Wer in die Zeiten schaut, und strebt,
> Nur der ist werth, zu sprechen und zu dichten.

Our universities are still far from the attainment of a proper combination of their resources between teaching and research. Even Oxford and Cambridge, which have done so much in recent years in the equipment of laboratories and in adding to their scientific staff, are still far behind a second-class German university. The professional faculties of the English universities are growing, and will diffuse a greater taste for science among their students, though they may absorb the time of the limited professoriate so as to prevent it advancing the boundaries of

knowledge. Professional faculties are absolutely essential to the existence of universities in poor countries like Scotland and Ireland. This has been the case from the early days of the Bologna University up to the present time. Originally universities arose not by mere bulls of popes, but as a response to the strong desire of the professional classes to dignify their crafts by real knowledge. If their education had been limited to mere technical schools like the Medical School of Salerno which flourished in the eleventh century, length but not breadth would have been given to education. So the universities wisely joined culture to the professional sciences. Poor countries like Scotland and Ireland must have their academic systems based on the professional faculties, although wealthy universities like Oxford and Cambridge may continue to have them as mere supplements to a more general education. A greater liberality of support on the part of the State in the establishment of chairs of science, for the sake of science and not merely for the teaching of the professions, would enable the poorer universities to take their part in the advancement of knowledge.

I have already alluded to the foundation of new colleges in different parts of the kingdom. Owens College has worthily developed into the Victoria University. Formerly she depended for degrees on the University of London. No longer will she be like a moon reflecting cold and sickly rays from a distant luminary, for in future she will be a sun, a centre of intelligence, warming and illuminating the regions around her. The other colleges which have formed themselves in large manufacturing districts are remarkable expressions from them that science must be promoted. Including the colleges of a high class, such as University College and King's College in London, and the three Queen's Colleges in Ireland, the aggregate attendance of students in colleges without university rank is between nine and ten thousand, while that of the universities is fifteen thousand. No doubt some of the provincial colleges require considerable improvement in their teaching methods; sometimes they unwisely aim at a full university curriculum when it would be better for them to act as faculties. Still they are all growing in the spirit of self-help, and some of them are destined, like Owens College, to develop into universities. This is not a subject of alarm to lovers of education, while it is one of hope and encouragement to the great centres of industry. There are too few autonomous universities in England in proportion to its population. While Scotland, with a population of $3\frac{3}{4}$ millions, has four universities with 6,500 students, England, with 26 millions of people, has only the same number of teaching universities with 6,000 students. Unless English colleges have such ambition, they may be turned into mere mills to grind out material for examinations and competitions. Higher colleges should always hold before their students that knowledge, for its own sake, is the only object worthy of reverence. Beyond college life there is a land of research flowing with milk and honey for those who know how to cultivate it.

Colleges should at least show a Pisgah view of this Land of Promise, which stretches far beyond the Jordan of examinations and competitions.

V. *Science and Industry.*

In the popular mind the value of science is measured by its applications to the useful purposes of life. It is no doubt true that science wears a beautiful aspect when she confers practical benefits upon man. But truer relations of science to industry are implied in Greek mythology. Vulcan, the god of industry, wooed science, in the form of Minerva, with a passionate love, but the chaste goddess never married, although she conferred upon mankind nearly as many arts as Prometheus, who, like other inventors, saw civilisation progressing by their use while he lay groaning in want on Mount Caucasus. The rapid development of industry in modern days depends on the applications of scientific knowledge, while its slower growth in former times was due to experiments being made by trial and error in order to gratify the needs of man. Then an experiment was less a questioning of Nature than an exercise on the mind of the experimentalist. For a true questioning of Nature only arises when intellectual conceptions of the causes of phenomena attach themselves to ascertained facts as well as to their natural environments. Much real science had at one time accumulated in Egypt, Greece, Rome, and Arabia, though it became obscured by the intellectual darkness which spread over Europe like a pall for many centuries. The mental results of Greek science, filtered through the Romans and Arabians, gradually fertilised the soil of Europe. Even in ages which are deemed to be dark and unprolific, substantial though slow progress was made. By the end of the fifteenth century the mathematics of the Alexandrian school had become the possession of Western Europe; Arabic numerals, algebra, trigonometry, decimal reckoning, and an improved calendar having been added to its stock of knowledge. The old discoveries of Democritus and Archimedes in physics, and of Hipparchus and Ptolemy in astronomy, were producing their natural developments, though with great slowness. Many manufactures, growing chiefly by experience, and occasionally lightened up by glimmerings of science throughout the prevailing darkness, had arisen before the sixteenth century. A knowledge of the properties of bodies, though scarcely of their relations to each other, came through the labours of the alchemists, who had a mighty impulse to work, for by the philosopher's stone, often not larger than half a rapeseed, they hoped to attain the three sensuous conditions of human enjoyment, gold, health, and immortality. By the end of the fifteenth century many important manufactures were founded by empirical experiment, with only the uncertain guidance of science. Among these were the compass, printing, paper, gunpowder, guns, watches, forks, knitting-needles, horseshoes, bells, wood cutting and copper engraving, wire-drawing, steel, table glass, spectacles, microscopes, glass mirrors backed by amalgams of tin and lead, windmills, crushing and saw mills. These

important manufactures arose from an increased knowledge of facts, around which scientific conceptions were slowly concreting. Aristotle defines this as science when he says, 'Art begins when, from a great number of experiences, one general conception is formed which will embrace all similar cases.' Such conceptions are formed only when culture develops the human mind and compels it to give a rational account of the world in which man lives, and of the objects in and around it, as well as of the phenomena which govern their action and evolution. Though the accumulation of facts is indispensable to the growth of science, a thousand facts are of less value to human progress than is a single one when it is scientifically comprehended, for it then becomes generalised in all similar cases. Isolated facts may be viewed as the dust of science. The dust which floats in the atmosphere is to the common observer mere incoherent matter in a wrong place, while to the man of science it is all-important when the rays of heat and light act upon its floating particles. It is by them that clouds and rains are influenced; it is by their selective influence on the solar waves that the blue of the heavens and the beauteous colours of the sky glorify all Nature. So, also, ascertained though isolated facts, forming the dust of science, become the reflecting media of the light of knowledge, and cause all Nature to assume a new aspect. It is with the light of knowledge that we are enabled to question Nature through direct experiment. The hypothesis or theory which induces us to put the experimental question may be right or wrong; still, *prudens questio dimidium scientiæ est*—it is half way to knowledge when you know what you have to inquire. Davy described hypothesis as the mere scaffolding of science, useful to build up true knowledge, but capable of being put up or taken down at pleasure. Undoubtedly a theory is only temporary, and the reason is, as Bacon has said, that the man of science 'loveth truth more than his theory.' The changing theories which the world despises are the leaves of the tree of science drawing nutriment to the parent stems, and enabling it to put forth new branches and to produce fruit; and though the leaves fall and decay, the very products of decay nourish the roots of the tree and reappear in the new leaves or theories which succeed.

When the questioning of Nature by intelligent experiment has raised a system of science, then those men who desire to apply it to industrial inventions proceed by the same methods to make rapid progress in the arts. They also must have means to compel Nature to reveal her secrets. Æneas succeeded in his great enterprise by plucking a golden branch from the tree of science. Armed with this even dread Charon dared not refuse a passage across the Styx; and the gate of the Elysian fields was unbarred when he hung the branch on its portal. Then new aspects of Nature were revealed—

> Another sun and stars they know
> That shine like ours, but shine below.

It is by carrying such a golden branch from the tree of science that in-

ventors are able to advance the arts. In illustration of how slowly at first and how rapidly afterwards science and its applications arise, I will take only two out of thousands of examples which lie ready to my hand. One of the most familiar instances is air, for that surely should have been soon understood if man's unaided senses are sufficient for knowledge. Air has been under the notice of mankind ever since the first man drew his first breath. It meets him at every turn; it fans him with gentle breezes, and it buffets him with storms. And yet it is certain that this familiar object—air—is very imperfectly understood up to the present time. We now know by recent researches that air can be liquefied by pressure and cold; but as a child still looks upon air as nothing, so did man in his early state. A vessel filled with air was deemed to be empty. But man, as soon as he began to speculate, felt the importance of air, and deemed it to be a soul of the world upon which the respiration of man and the god-like quality of fire depended. Yet a really intelligent conception of these two essential conditions to man's existence—respiration and combustion—was not formed till about a century ago (1775). No doubt long before that time there had been abundant speculations regarding air. Anaximenes, 548 years before Christ, and Diogenes of Apollonia, a century later, studied the properties of air so far as their senses would allow them; so, in fact, did Aristotle. Actual scientific experiments were made on air about the year 1100 by a remarkable Saracen, Alhazen, who ascertained important truths which enabled Galileo, Torricelli, Otto de Guericke, and others at a later period to discover laws leading to important practical applications. Still there was no intelligent conception as to the composition of air until Priestley in 1774 repeated, with the light of science, an empirical observation which Eck de Sulbach had made three hundred years before upon the union of mercury with an ingredient of air and the decomposition of this compound by heat. This experiment now proved that the active element in air is oxygen. From that date our knowledge, derived from an intelligent questioning of air by direct experiments, has gone on by leaps and bounds. The air, which mainly consists of nitrogen and oxygen, is now known to contain carbonic acid, ammonia, nitric acid, ozone, besides hosts of living organisms which have a vast influence for good or evil in the economy of the world. These micro-organisms, the latest contribution to our knowledge of air, perform great analytical functions in organic nature, and are the means of converting much of its potential energy into actual energy. Through their action on dead matter the mutual dependence of plants and animals is secured, so that the air becomes at once the grave of organic death and the cradle of organic life. No doubt the ancients suspected this without being able to prove the dependence. Euripides seems to have seen it deductively when he describes the results of decay:—

> Then that which springs from earth, to earth returns,
> And that which draws its being from the sky
> Rises again up to the skyey height

The consequences of the progressive discoveries have added largely to our knowledge of life, and have given a marvellous development to the industrial arts. Combustion and respiration govern a wide range of processes. The economical use of fuel, the growth of plants, the food of animals, the processes of husbandry, the maintenance of public health, the origin and cure of disease, the production of alcoholic drinks, the processes of making vinegar and saltpetre—all these and many other kinds of knowledge have been brought under the dominion of law. No doubt animals respired, fuel burned, plants grew, sugar fermented, before we knew how they depended upon air. But as the knowledge was empirical, it could not be intelligently directed. Now all these processes are ranged in order under a wise economy of Nature, and can be directed to the utilities of life; for it is true, as Swedenborg says, that 'human ends always ascend as Nature descends.' There is scarcely a large industry in the world which has not received a mighty impulse by the better knowledge of air acquired within a hundred years. If I had time I could show still more strikingly the industrial advantages which have followed from Cavendish's discovery of the composition of water. I wish that I could have done this, because it was Addison who foolishly said, and Paley who as unwisely approved the remark, 'that mankind required to know no more about water than the temperature at which it froze and boiled, and the mode of making steam.'

When we examine the order of progress in the arts, even before they are illumined by science, their improvements seem to be the resultants of three conditions.

1. The substitution of natural forces for brute animal power, as when Hercules used the waters of the Alpheus to cleanse the Augean stables; or when a Kamchadal of Eastern Asia, who has been three years hollowing out a canoe, finds that he can do it in a few hours by fire.

2. The economy of time, as when a calendering machine produces the same gloss to miles of calico that an African savage gives to a few inches by rubbing it with the shell of a snail; or the economy of production, as when steel pens, sold when first introduced at one shilling apiece, are now sold at a penny per dozen; or when steel rails, lately costing 45*l.* per ton, can now be sold at 5*l.*

3. Methods of utilising waste products, or of endowing them with properties which render them of increased value to industry, as when waste scrap iron and the galls on the oak are converted into ink; or the badly-smelling waste of gasworks is transformed into fragrant essences, brilliant dyes, and fertilising manure; or when the effete matter of animals or old bones is changed into lucifer-matches.

All three results are often combined when a single end is obtained—at all events, economy of time and production invariably follows when natural forces substitute brute animal force. In industrial progress the sweat of the brow is lessened by the conceptions of the brain. How

exultant is the old Greek poet, Antipater,[1] when women are relieved of the drudgery of turning the grindstones for the daily supply of corn. 'Woman! you who have hitherto had to grind corn, let your arms rest for the future. It is no longer for you that the birds announce by their songs the dawn of the morning. Ceres has ordered the *water-nymphs* to move the heavy millstones and perform your labour.' Penelope had twelve slaves to grind corn for her small household. During the most prosperous time of Athens it was estimated that there were twenty slaves to each free citizen. Slaves are mere machines, and machines neither invent nor discover. The bondmen of the Jews, the helots of Sparta, the captive slaves of Rome, the serfs of Europe, and uneducated labourers of the present day who are the slaves of ignorance have added nothing to human progress. But as natural forces substitute and become cheaper than slave labour, liberty follows advancing civilisation. Machines require educated superintendence. One shoe factory in Boston by its machines does the work of thirty thousand shoemakers in Paris who have still to go through the weary drudgery of mechanical labour. The steam power of the world, during the last twenty years, has risen from $11\frac{1}{2}$ million to 29 million horse-power, or 152 per cent.

Let me take a single example of how even a petty manufacture improved by the teachings of science affects the comforts and enlarges the resources of mankind. When I was a boy, the only way of obtaining a light was by the tinder-box, with its quadruple materials, flint and steel, burnt rags or tinder, and a sulphur-match. If everything went well, if the box could be found and the air was dry, a light could be obtained in two minutes; but very often the time occupied was much longer, and the process became a great trial to the serenity of temper. The consequence of this was that a fire or a burning lamp was kept alight through the day. Old Gerard, in his Herbal, tells us how certain fungi were used to carry fire from one part of the country to the other. The tinder-box long held its position as a great discovery in the arts. The *Pyxidicula Igniaria* of the Romans appears to have been much the same implement as, though a little ruder than, the flint and steel which Philip the Good put into the collar of the Golden Fleece in 1429 as a representation of high knowledge in the progress of the arts. It continued to prevail till 1833, when phosphorus-matches were introduced; though I have been amused to find that there are a few venerable ancients in London who still stick to the tinder-box, and for whom a few shops keep a small supply. Phosphorus was no new discovery, for it had been obtained by an Arabian called Bechel in the eighth century. However, it was forgotten, and was rediscovered by Brandt, who made it out of very stinking materials in 1669. Other discoveries had, however, to be made before it could be used for lucifer-matches. The science of combustion was only developed on the discovery of oxygen a century later. Time had to elapse before chemical analysis showed the kind of bodies

[1] *Analecta Veterum Græcorum*, Epig. 39, vol. ii. p. 119.

which could be added to phosphorus so as to make it ignite readily. So it was not till 1833 that matches became a partial success. Intolerably bad they then were, dangerously inflammable, horribly poisonous to the makers and injurious to the lungs of the consumers. It required another discovery by Schrötter in 1845 to change poisonous waxy into innocuous red-brick phosphorus in order that these defects might be remedied, and to give us the safety-match of the present day. Now what have these successive discoveries in science done for the nation, in this single manufacture, by an economy of time? If before 1833 we had made the same demands for light that we now do, when we daily consume eight matches per head of the population, the tinder-box could have supplied the demand under the most favourable conditions by an expenditure of one quarter of an hour. The lucifer-match supplies a light in fifteen seconds on each occasion, or in two minutes for the whole day. Putting these differences into a year, the venerable ancient who still sticks to his tinder-box would require to spend ninety hours yearly in the production of light, while the user of lucifer-matches spends twelve hours; so that the latter has an economy of seventy-eight hours yearly, or about ten working days. Measured by cost of production at one shilling and sixpence daily, the economy of time represented in money to our population is twenty-six millions of pounds annually. This is a curious instance of the manner in which science leads to economy of time and wealth even in a small manufacture. In larger industries the economy of time and labour produced by the application of scientific discoveries is beyond all measurement. Thus the discovery of latent heat by Black led to the inventions of Watt; while that of the mechanical equivalent of heat by Joule has been the basis of the progressive improvements in the steam-engine which enables power to be obtained by a consumption of fuel less than one-fourth the amount used twenty years ago. It may be that the engines of Watt and Stephenson will yield in their turn to more economical motors; still they have already expanded the wealth, resources, and even the territories of England more than all the battles fought by her soldiers or all the treaties negotiated by her diplomatists.

The coal which has hitherto been the chief source of power probably represents the product of five or six million years during which the sun shone upon the plants of the Carboniferous Period, and stored up its energy in this convenient form. But we are using this conserved force wastefully and prodigally; for, although horse-power in steam engines has so largely increased since 1864, two men only now produce what three men did at that date. It is only three hundred years since we became a manufacturing country. According to Professor Dewar, in less than two hundred years more the coal of this country will be wholly exhausted, and in half that time will be difficult to procure. Our not very distant descendants will have to face the problem—What will be the condition of England without coal? The answer to that question depends upon the intellectual development of the nation at that time. The value of the in-

tellectual factor of production is continually increasing; while the values of raw material and fuel are lessening factors. It may be that when the dreaded time of exhausted fuel has arrived, its importation from other coal-fields, such as those of New South Wales, will be so easy and cheap that the increased technical education of our operatives may largely overbalance the disadvantages of increased cost in fuel. But this supposes that future Governments in England will have more enlightened views as to the value of science than past Governments have possessed.

Industrial applications are but the overflowings of science welling over from the fulness of its measure. Few would ask now, as was constantly done a few years ago, 'What is the use of an abstract discovery in science?' Faraday once answered this question by another, 'What is the use of a baby?' Yet round that baby centre all the hopes and sentiments of his parents, and even the interests of the State, which interferes in its upbringing so as to ensure it being a capable citizen. The processes of mind which produce a discovery or an invention are rarely associated in the same person, for while the discoverer seeks to explain causes and the relations of phenomena, the inventor aims at producing new effects, or at least of obtaining them in a novel and efficient way. In this the inventor may sometimes succeed without much knowledge of science, though his labours are infinitely more productive when he understands the causes of the effects which he desires to produce.

A nation in its industrial progress, when the competition of the world is keen, cannot stand still. Three conditions only are possible for it. It may go forward, retrograde, or perish. Its extinction as a great nation follows its neglect of higher education, for, as described in the proverb of Solomon, 'They that hate instruction love death.' In sociology, as in biology, there are three states. The first of balance, when things grow neither better nor worse; the second that of elaboration or evolution, as we see it when animals adapt themselves to their environments; and the third, that of degeneration, when they rapidly lose the ground they have made. For a nation, a state of balance is only possible in the early stage of its existence, but it is impossible when its environments are constantly changing.

The possession of the raw materials of industry and the existence of a surplus population are important factors for the growth of manufactures in the early history of a nation, but afterwards they are bound up with another factor—the application of intellect to their development. England could not be called a manufacturing nation till the Elizabethan age. No doubt coal, iron, and wool were in abundance, though, in the reign of the Plantagenets, they produced little prosperity. Wool was sent to Flanders to be manufactured, for England then stood to Holland as Australia now does to Yorkshire. The political crimes of Spain from the reign of Ferdinand and Isabella to that of Philip III. destroyed it as a great manufacturing nation, and indirectly led to England taking its position. Spain, through the activity and science of the Arabian intellect,

had acquired many important industries. The Moors and the Moriscoes, who had been in Spain for a period as long as from the Norman Conquest of this country to the present date, were banished, and with them departed the intellect of Spain. Then the invasion of the Low Countries by Philip II. drove the Flemish manufacturers to England, while the French persecution of the Huguenots added new manufacturing experience, and with them came the industries of cotton, wool, and silk. Cotton mixed with linen and wool became freely used, but it was only from 1738 to the end of the century that the inventions of Wyatt, Arkwright, Hargreaves, Crompton, and Cartwright started the wonderful modern development. The raw cotton was imported from India or America, but that fact as regards cost was a small factor in comparison with the intellect required to convert it into a utility. Science has in the last hundred years altered altogether the old conditions of industrial competition. She has taught the rigid metals to convey and record our thoughts even to the most distant lands, and, within less limits, to reproduce our speech. This marvellous application of electricity has diminished the cares and responsibilities of Governments, while it has at the same time altered the whole practice of commerce. To England steam and electricity have been of incalculable advantage. The ocean, which once made the country insular and isolated, is now the very life-blood of England and of the greater England beyond the seas. As in the human body the blood bathes all its parts, and through its travelling corpuscles carries force to all its members, so in the body politic of England and its pelagic extensions, steam has become the circulatory and electricity the nervous system. The colonies, being young countries, value their raw materials as their chief sources of wealth. When they become older they will discover it is not in these, but in the culture of scientific intellect, that their future prosperity depends. Older nations recognise this as the law of progress more than we do; or, as Jules Simon tersely puts it—'That nation which most educates her people will become the greatest nation, if not to-day, certainly to-morrow.' Higher education is the condition of higher prosperity, and the nation which neglects to develop the intellectual factor of production must degenerate, for it cannot stand still. If we felt compelled to adopt the test of science given by Comte, that its value must be measured by fecundity, it might be prudent to claim industrial inventions as the immediate fruit of the tree of science, though only fruit which the prolific tree has shed. But the test is untrue in the sense indicated, or rather the fruit, according to the simile of Bacon, is like the golden apples which Aphrodite gave to the suitor of Atalanta, who lagged in her course by stooping to pick them up, and so lost the race. The true cultivators of the tree of science must seek their own reward by seeing it flourish, and let others devote their attention to the possible practical advantages which may result from their labours.

There is, however, one intimate connection between science and industry which I hope will be more intimate as scientific education becomes

more prevalent in our schools and universities. Abstract science depends on the support of men of leisure, either themselves possessing or having provided for them the means of living without entering into the pursuits of active industry. The pursuit of science requires a superfluity of wealth in a community beyond the needs of ordinary life. Such superfluity is also necessary for art, though a picture or a statue is a saleable commodity, while an abstract discovery in science has no immediate or, as regards the discoverer, proximate commercial value. In Greece, when philosophical and scientific speculation was at its highest point, and when education was conducted in its own vernacular and not through dead languages, science, industry, and commerce were actively prosperous. Corinth carried on the manufactures of Birmingham and Sheffield, while Athens combined those of Leeds, Staffordshire, and London, for it had woollen manufactures, potteries, gold and silver work, as well as shipbuilding. Their philosophers were the sons of burghers, and sometimes carried on the trades of their fathers. Thales was a travelling oil merchant, who brought back science as well as oil from Egypt. Solon and his great descendant Plato, as well as Zeno, were men of commerce. Socrates was a stone-mason; Thucydides a gold-miner; Aristotle kept a druggist's shop until Alexander endowed him with the wealth of Asia. All but Socrates had a superfluity of wealth, and he was supported by that of others. Now if our universities and schools created that love of science which a broad education would surely inspire, our men of riches and leisure who advance the boundaries of scientific knowledge could not be counted on the fingers as they now are, when we think of Boyle, Cavendish, Napier, Lyell, Murchison, and Darwin, but would be as numerous as our statesmen and orators. Statesmen, without a following of the people who share their views and back their work, would be feeble indeed. But while England has never lacked leaders in science, they have too few followers to risk a rapid march. We might create an army to support our generals in science, as Germany has done, and as France is now doing, if education in this country would only mould itself to the needs of a scientific age. It is with this feeling that Horace Mann wrote:—'The action of the mind is like the action of fire; one billet of wood will hardly burn alone, though as dry as the sun and north-west wind can make it, and though placed in a current of air; ten such billets will burn well together, but a hundred will create a heat fifty times as intense as ten—will make a current of air to fan their own flame, and consume even greenness itself.'

VI. *Abstract Science the Condition for Progress.*

The subject of my address has been the relations of science to the public weal. That is a very old subject to select for the year 1885. I began it by quoting the words of an illustrious prince, the consort of our Queen, who addressed us on the same subject from this platform twenty-six years ago. But he was not the first prince who saw how closely science

is bound up with the welfare of States. Ali, the son-in-law of Mahomet, the fourth successor to the Caliphate, urged upon his followers that men of science and their disciples give security to human progress. Ali loved to say, 'Eminence in science is the highest of honours,' and 'He dies not who gives life to learning.' In addressing you upon texts such as these, my purpose was to show how unwise it is for England to lag in the onward march of science when most other European Powers are using the resources of their States to promote higher education and to advance the boundaries of knowledge. English Governments alone fail to grasp the fact that the competition of the world has become a competition in intellect. Much of this indifference is due to our systems of education. I have ill fulfilled my purpose if, in claiming for science a larger share in public education, I have in any way depreciated literature, art, or philosophy, for every subject which adds to culture aids in human development. I only contend that in public education there should be a free play to the scientific faculty, so that the youths who possess it should learn the richness of their possession during the educative process. The same faculties which make a man great in any walk of life—strong love of truth, high imagination tempered by judgment, a vivid memory which can co-ordinate other facts with those under immediate consideration—all these are qualities which the poet, the philosopher, the man of literature, and the man of science equally require and should cultivate through all parts of their education as well as in their future careers. My contention is that science should not be practically shut out from the view of a youth while his education is in progress, for the public weal requires that a large number of scientific men should belong to the community. This is necessary because science has impressed its character upon the age in which we live, and as science is not stationary but progressive, men are required to advance its boundaries, acting as pioneers in the onward march of States. Human progress is so identified with scientific thought, both in its conception and realisation, that it seems as if they were alternative terms in the history of civilisation. In literature, and even in art, a standard of excellence has been attained which we are content to imitate because we have been unable to surpass. But there is no such standard in science. Formerly, when the dark cloud was being dissipated which had obscured the learning of Greece and Rome, the diffusion of literature or the discovery of lost authors had a marked influence on advancing civilisation. Now, a Chrysoloras might teach Greek in the Italian universities without hastening sensibly the onward march of Italy; a Poggio might discover copies of Lucretius and Quintilian without exercising a tithe of the influence on modern life that an invention by Stephenson or Wheatstone would produce. Nevertheless, the divorce of culture and science, which the present state of education in this country tends to produce, is deeply to be deplored, because a cultured intelligence adds greatly to the development of the scientific faculty. My argument is that no amount of learning without science suffices in the present state

of the world to put us in a position which will enable England to keep ahead or even on a level with foreign nations as regards knowledge and its applications to the utilities of life. Take the example of any man of learning, and see how soon the direct consequences resulting from his learning disappear in the life of a nation, while the discoveries of a man of science remain productive amid all the shocks of empire. As I am in Aberdeen I remember that the learned Dutchman Erasmus was introduced to England by the encouragement which he received from Hector Boece, the Principal of King's College in this University. Yet even in the case of Erasmus—who taught Greek at Cambridge and did so much for the revival of classical literature as well as in the promotion of spiritual freedom—how little has civilisation to ascribe to him in comparison with the discoveries of two other Cambridge men, Newton and Cavendish. The discoveries of Newton will influence the destinies of mankind to the end of the world. When he established the laws by which the motions of the great masses of matter in the universe are governed, he conferred an incalculable benefit upon the intellectual development of the human race. No great discovery flashes upon the world at once, and therefore Pope's lines on Newton are only a poetic fancy :—

> Nature and Nature's laws lay hid in night,
> God said, 'Let Newton be,' and all was light.

No doubt the road upon which he travelled had been long in preparation by other men. The exact observations of Tycho Brahe, coupled with the discoveries of Copernicus, Kepler, and Galileo, had already broken down the authority of Aristotle and weakened that of the Church. But though the conceptions of the universe were thus broadened, mankind had not yet rid themselves of the idea that the powers of the universe were still regulated by spirits or special providences. Even Kepler moved the planets by spirits, and it took some time to knock these celestial steersmen on the head. Descartes, who really did so much by his writings to force the conclusion that the planetary movements should be dealt with as an ordinary problem in mechanics, looked upon the universe as a machine, the wheels of which were kept in motion by the unceasing exercise of a divine power. Yet such theories were only an attempt to regulate the universe by celestial intelligences like our own, and by standards within our reach. It required the discovery of an all-pervading law, universal throughout all space, to enlarge the thoughts of men, and one which, while it widened the conceptions of the universe, reduced the earth and solar system to true dimensions. It is by the investigation of the finite on all sides that we obtain a higher conception of the infinite—

> Willst du ins Unendliche schreiten,
> Geh nur im Endlichen nach allen Seiten.

Ecclesiastical authority had been already undermined by earnest inquirers such as Wycliffe and Huss before Luther shook the pillars of the Vatican.

They were removers of abuses, but were confined within the circles of their own beliefs. Newton's discovery cast men's minds into an entirely new mould, and levelled many barriers to human progress. This intellectual result was vastly more important than the practical advantages of the discovery. It is true that navigation and commerce mightily benefited by our better knowledge of the motions of the heavenly bodies. Still, these benefits to humanity are incomparably less in the history of progress than the expansion of the human intellect which followed the withdrawal of the cramps that confined it. Truth was now able to discard authority, and marched forward without hindrance. Before this point was reached Bruno had been burned, Galileo had abjured, and both Copernicus and Descartes had kept back their writings for fear of offending the Church.

The recent acceptance of evolution in biology has had a like effect in producing a far profounder intellectual change in human thought than any mere impulse of industrial development. Already its application to sociology and education is recognised, but that is of less import to human progress than the broadening of our views of Nature.

Abstract discovery in science is then the true foundation upon which the superstructure of modern civilisation is built; and the man who would take part in it should study science, and, if he can, advance it for its own sake and not for its applications. Ignorance may walk in the path lighted by advancing knowledge, but she is unable to follow when science passes her; for, like the foolish virgin, she has no oil in her lamp.

An established truth in science is like the constitution of an atom in matter—something so fixed in the order of things that it has become independent of further dangers in the struggle for existence. The sum of such truths forms the intellectual treasure which descends to each generation in hereditary succession. Though the discoverer of a new truth is a benefactor to humanity, he can give little to futurity in comparison with the wealth of knowledge which he inherited from the past. We, in our generation, should appreciate and use our great possessions—

For me your tributary stores combine,
Creation's heir; the world, the world is mine.

REPORTS

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Report of the Committee, consisting of Professor G. CAREY FOSTER, Sir W. THOMSON, Professor AYRTON, Professor J. PERRY, Professor W. G. ADAMS, Lord RAYLEIGH, Dr. O. J. LODGE, Dr. JOHN HOPKINSON, Dr. A. MUIRHEAD, Mr. W. H. PREECE, Mr. H. TAYLOR, Professor EVERETT, Professor SCHUSTER, Dr. J. A. FLEMING, Professor G. F. FITZGERALD, Mr. R. T. GLAZEBROOK (*Secretary*), Professor CHRYSTAL, Mr. H. TOMLINSON, *and* Professor W. GARNETT, *appointed for the purpose of constructing and issuing practical Standards for use in Electrical Measurements.*

THE Committee report that during the year the standards of resistance, in terms of the legal ohm referred to in the last Report, have been constructed, and their values determined in accordance with the resolution adopted on June 25, 1884.

The one-ohm standards were generally referred to the original B.A. units of the Association by combining in multiple arc with the standard one of the 100 B.A. units, and determining by Carey Foster's method the difference between the combination and a B.A. unit, and then assuming, in accordance with the resolution, that 1 B.A. unit = ·9889 legal ohm.

The following values were thus found for the two standards.

The temperatures were taken by a thermometer graduated to tenths of a degree centigrade, which had been compared with the Kew standards.

Resistance Coil, Elliott, No. 139, Ω 100.

Date	Temperature	Resistance
Nov. 24, 1884	11°·4	·99878
„ 26, „	11°·6	·99890
„ 27, „	12°·9	·99916
„ 28, „	13°·5	·99930
Dec. 5, „	13°·5	·99931
„ 12, „	15°·3	·99979
July 30, 1885 . . .	17°·2	1·00027
„ 28, „	18°·1	1·00061

Mean value . . . . . . ·999515, at 14°·1 C.
Temperature coefficient . . ·000271

Resistance Coil, Elliott, No. 140, B.A. 101.

Date	Temperature	Resistance
Nov. 24, 1884 . . .	11°·4	·99813
„ 25, „ . . .	11°·5	·99815
Dec. 2, „ . . .	12°·8	·99847
Nov. 27, „ . . .	12°·9	·99851
Dec. 5, „ . . .	13°·4	·99865
„ 12, „ . . .	15°·4	·99917
July 30, 1885 . . .	17°·2	·99961
„ 29, „ . . .	18°·0	·99983

Mean value . . . . . . ·998815, at 14°·1 C.
Temperature coefficient . . ·000259

The ten-ohm standards were then compared with the one-ohm by means of the arrangement suggested by Lord Rayleigh, and described in the Report for 1883, and from these values were obtained for the coils of higher resistance.

The results are contained below.

No. of Coil	Resistance	Temperature
No. 141, B.A. No. 102 .	10·00103	16°·7
No. 142, B.A. No. 103 .	10·00169	16°·75
No. 143, B.A. No. 104 .	99·9977	16°·05
No. 144, B.A. No. 105 .	100·0108	16°·05
No. 145, B.A. No. 106 .	1,000·306	17°·4
No. 146, B.A. No. 107 .	1,000·276	17°·4
No. 147, B.A. No. 108 .	10,002·4	17°·35
No. 148, B.A. No. 109 .	10,002·4	17°·35

These experiments were carried out at the Cavendish Laboratory by the Secretary and Mr. H. Wilson, of St. John's College.

At the request of M. Mascart, the Secretary compared with the legal ohms of the Association three mercury copies of a legal ohm, constructed by M. J. R. Benoit, of Paris. A detailed account of these experiments was laid before the Physical Society.[1] The values found are given below.

No. of Tubes	Value found by M. J. R. Benoit	Value found by R. T. G.	Diff
37	1·00045	·99990	·00055
38	1·00066	1·00011	·00055
39	·99954	·99917	·00037
Mean	1·00022	·99972	·00049

[1] *Phil. Mag.* Oct. 1885.

The work of testing resistance-coils has been continued, and a table of the values found for the various coils examined is given.

British Association Units.

No. of Coil	Resistance in B.A. Units	Temperature
Elliott, No. 122	10·0163	19°·8
No. 61	10·0017	15°·2
	9·9885	10°·5
Elliott, No. 58	9·9834	14°·05

Legal Ohms.

No. of Coil	Resistance in Legal Ohms	Temperature
No. 150	·99895	11°·7
No. 151	·99974	13°·9
Elliott, 149, No. 152	·99912	12°·5
Elliott, 136, No. 153	·99977	12°·4
No. 154	1·00032	17°·3

The Committee hope that arrangements may be made for issuing standards of electro-motive force and constructing standards of capacity. In conclusion, they would ask to be reappointed, with the addition of the names of Professor J. J. Thomson and Mr. W. N. Shaw, with the renewal of the unexpended grant of 50*l.*

Report of the Committee, consisting of Professors A. JOHNSON (*Secretary*), J. G. MACGREGOR, J. B. CHERRIMAN, H. T. BOVEY, *and* Mr. C. CARPMAEL, *appointed for the purpose of promoting Tidal Observations in Canada.*

THE Committee have represented to the Canadian Government the importance of publishing tide-tables for Canadian waters, and the necessity for this purpose of establishing stations for continuous tidal observations, recommending that the observations be subsequently reduced by the methods of the British Association.

They have pointed to the example of the United States Government, which has provided tide-tables for both the Atlantic and Pacific coasts.

In urging the practical side of the question they have more especially referred to the tide-tables for British and Irish ports published by the Admiralty, which give the rate and set of the tidal currents in the waters surrounding the British islands; and they have drawn attention to the heavy annual losses caused by ignorance of these currents in Canadian waters, as shown by the wreck list.

In order to strengthen their representation from this point of view, they deemed it well to get the opinions of Boards of Trade and shipowners and shipmasters. On inquiry it appeared that the Montreal Board of Trade were at the very time considering the question, which had been brought independently before them. On learning the object of the Committee they gave it their most hearty support, and addressed a strong memorial on the subject to the Dominion Government.

The Boards of Trade of the other chief ports of the Dominion also sent similar memorials. The shipowners and masters of ships, to whom application was made, were practically unanimous in their testimony as to the pressing need for knowledge on the subject.

The representations of your Committee were made through the Minister of Marine, with whom an interview was obtained, at which a memorial was submitted. Copies of the answers of the shipmasters (a large number of which had been received) were submitted at the same time. Full explanations, in reply to the inquiries of the Minister, were given, more especially on practical points connected with the proposed observations at fixed stations and the reductions, for which your Committee are largely indebted to a corresponding committee appointed by the Council, consisting of the Right Hon. Sir Lyon Playfair, Professor J. Couch Adams, Sir William Thomson, and Professor Darwin.

During the session of Parliament the Royal Society of Canada also addressed petitions to the Governor-General and the two Houses of Parliament, strongly urging the need of tidal observations.

The reply of the Minister of Marine stated that, owing to the large outlay on the Georgian Bay Survey, and on the expedition to Hudson's Bay during the past summer (1885), the Government did not propose to take action in the matter of tidal observations at present. This unfavourable answer, it will be observed, is made to depend on a temporary financial condition, and your Committee have reason to believe that if the financial prospects improve by next session of Parliament, the Government will take the matter into earnest consideration; they therefore suggest that the Committee be reappointed.

Fifth Report of the Committee, consisting of Mr. JOHN MURRAY (*Secretary*), Professor SCHUSTER, Professor Sir WILLIAM THOMSON, Professor Sir H. E. ROSCOE, Professor A. S. HERSCHEL, Captain W. DE W. ABNEY, Professor BONNEY, Mr. R. H. SCOTT, *and* Dr. J. H. GLADSTONE, *appointed for the purpose of investigating the practicability of collecting and identifying Meteoric Dust, and of considering the question of undertaking regular observations in various localities.*

THE Secretary reported that collecting apparatus had been sent to various oceanic islands, and that a report would be prepared by next year on the specimens received.

Third Report of the Committee, consisting of Professors G. H. Darwin *and* J. C. Adams, *for the Harmonic Analysis of Tidal Observations. Drawn up by* Professor G. H. Darwin.

I. Record of Work during the past Year.

The edition of the computation forms referred to in the second report is now completed, and copies are on sale with the Cambridge Scientific Instrument Company, St. Tibbs' Row, Cambridge, at the price of 2*s.* 6*d.* each. Some copies of the first report, in which the theory and use of these forms are explained, are also on sale at the same price. A few copies of the computation forms have been sent to the librarians of some of the principal Scientific Academies of Europe and America.[1]

In South Africa, Mr. Gill, at the Cape, and Mr. Neison, at Natal, are now engaged in reducing observations with forms supplied from this edition.

A memorial has been addressed to the Government of the Dominion of Canada, urging the desirability of systematic tidal observation, and the publication of tide-tables for the Canadian coasts. There seems to be good hope that a number of tide-gauges will shortly be set up on the Atlantic and Pacific coasts, and in the Gulf of the St. Lawrence. The observations will probably be reduced according to the methods of the British Association, and the predictions made with the instrument of the Indian Government.

Major Baird has completed the reduction of all the tidal results obtained at the Indian stations to the standard form proposed in the Report of 1883, and Mr. Roberts has similarly reduced a few results read before the Association by Sir William Thomson and Captain Evans in 1878. All these are now being published in the 'Proceedings of the Royal Society,' in a paper by Major Baird and myself.

A large number of tidal results have been obtained by the United States Coast Survey, and reduced under the superintendence of Professor Ferrel. Although the method pursued by him has been slightly different from that of the British Association, it appears that the American results should be comparable with those at the Indian and European ports. Professor Ferrel has given an assurance that this is the case; nevertheless, there appears to be strong internal evidence that, at some of the ports, some of the phases should be altered by 180°. The doubt thus raised will probably be removed, and the paper before the Royal Society will afford a table of reference for all—or nearly all—the results of the harmonic method up to the date of its publication.

The manual of tidal observation promised by Major Baird is now completed, and will be published shortly. This work will explain fully all the practical difficulties likely to be encountered in the choice of a station for a tide-gauge, and in the erection and working of the instrument. Major Baird's great experience in India, and the success with which the operations of which he has had charge have been carried out, render his

[1] Namely, the Royal Societies of London and Edinburgh, the Royal Irish Academy, the Academies of Paris, Berlin, and Vienna, the United Coast Survey, and the Cambridge Philosophical Society.

advice of great value for the prosecution of tidal observation in other countries. The work also explains the method of measuring the tide diagrams, entering the figures in the computation forms, and the subsequent numerical operations.

II. Certain Factors and Angles used in the Reduction of Tidal Observations.

In completing the reduction of the results of harmonic analysis to the standard form, a number of angles and factors are required which depend on the longitude of the moon's node. Tables of these angles and factors have been computed under the superintendence of Major Baird.[1] It may happen, however, that the tables are inaccessible to the computer, and the computation from the full formulæ might be somewhat laborious. It happens that the angles ν, ξ, ν', $2\nu''$ (the meanings of which are explained in the Report of 1883) are all expressible in the form

$$\text{A} \sin N + \text{B} \sin 2N + \text{C} \sin 3N + \ldots\ldots,$$

where N is the longitude of the moon's node, and that the coefficients diminish with such rapidity that the first two terms are probably sufficient for all practical purposes.

Also the several factors f are reducible to the form

$$\text{A} + \text{B} \cos N + \text{C} \cos 2N + \ldots\ldots,$$

and three terms are practically sufficient.

I have obtained the approximate formulæ given below in this form. The rigorous results having been tabulated, it appeared easier to work from them instead of from analytical expressions in terms of the longitude of the moon's node. I find, then, the following results:—

Schedule I. *Approximate Formulæ for Angles.*

$$\nu = 12^\circ{\cdot}9 \sin N - 1^\circ{\cdot}3 \sin 2N,$$

$$\xi = \nu - 1^\circ{\cdot}07 \sin N,$$

$$(\text{for } K_1) \quad \nu' = 8^\circ{\cdot}8 \sin N - 0^\circ{\cdot}6 \sin 2N,$$

$$(\text{for } K_2) \quad 2\nu'' = 17^\circ{\cdot}8 \sin N - 0^\circ{\cdot}5 \sin 2N.$$

Also $\Delta = 16^\circ{\cdot}51 + 3^\circ{\cdot}44 \cos N - 0^\circ{\cdot}19 \cos 2N$, and $\Delta_{,} = 16^\circ{\cdot}36$.

For the meanings of Δ and $\Delta_{,}$ the reader must refer to Part IV.

Approximate Formulæ for Factors f.

For M_2 and other tides,

$$\text{f} = \frac{\cos^4 \frac{1}{2} I}{\cos^4 \frac{1}{2}\omega \cos^4 \frac{1}{2} i} = 1{\cdot}0003 - {\cdot}0373 \cos N + {\cdot}0002 \cos 2N.$$

For O, $\text{f} = \dfrac{\sin I \cos^2 \frac{1}{2} I}{\sin \omega \cos^2 \frac{1}{2}\omega \cos^4 \frac{1}{2} i} = 1{\cdot}0088 + {\cdot}1886 \cos N - {\cdot}0146 \cos 2N.$

For K_2 . . . . $\text{f} = 1{\cdot}0243 + {\cdot}2847 \cos N + {\cdot}0080 \cos 2N.$

For K_1 . . . . $\text{f} = 1{\cdot}0060 + {\cdot}1156 \cos N - {\cdot}0088 \cos 2N.$

For Mf . . $\text{f} = \dfrac{\sin^2 I}{\sin^2 \omega \cos^4 \frac{1}{2} i} = 1{\cdot}0429 + {\cdot}4135 \cos N - {\cdot}0040 \cos 2N.$

[1] Some of these are given in the Report of 1883.

For Mm,

$$f=\frac{1-\frac{3}{2}\sin^2 I}{(1-\frac{3}{2}\sin^2\omega)(1-\frac{3}{2}\sin^2 i)}=1{\cdot}0000-{\cdot}1299\cos N+{\cdot}0013\cos 2N.$$

Even if all the terms in $2N$ were omitted, the approximations might be good enough for all practical purposes.

III. On the Periods chosen for Harmonic Analysis in the Computation Forms.

Before proceeding to the subject of this section, it may be remarked that it is unfortunate that the days of the year in the computation forms should have been numbered from unity upwards, instead of from zero, as in the case of the hours. It would have been preferable that the first entry should have been numbered Day 0, Hour 0, instead of Day 1, Hour 0. This may be rectified with advantage if ever a new issue of the forms is required, but the existing notation is adhered to in this section.

The computation form for each tide consists of pages for entry of the hourly tide-heights, in which the entries are grouped according to rules appropriate to that tide. The forms terminate with a broken number of hours. This, as we shall now show, is erroneous, although this error may not be of much practical importance.

In § 9 of the Report for 1883 the following passage occurs :—

'The elimination of the effects of the other tides may be improved by choosing the period for analysis not exactly equal to one year. For suppose that the expression for the height of water is

$$A_1\cos n_1t+B_1\sin n_1t+A_2\cos n_2t+B_2\sin n_2t \quad . \quad . \quad . \quad (61)$$

'where n_2 is nearly equal to n_1, and that we wish to eliminate the n_2-tide, so as to be left only with the n_1-tide.

'Now, this expression is equal to

$$\left.\begin{array}{l}\{A_1+A_2\cos(n_1-n_2)t-B_2\sin(n_1-n_2)t\}\cos n_1t\\ +\{B_1+A_2\sin(n_1-n_2)t+B_2\cos(n_1-n_2)t\}\sin n_1t\end{array}\right\} \quad . \quad . \quad (62)$$

'That is to say, we may regard the tide as oscillating with a speed n_1, but with slowly varying range.'

Although this is thus far correct, yet the subsequent justification of the plan according to which the computation forms have been compiled is wrong.

In the column appertaining to any hour in the form we have n_1t a multiple of 15°, if n_1 be a diurnal, and of 30°, if n_1 be a semidiurnal tide.

Consider the column headed 'p-hours'; then $n_1t=15°p$ for diurnals, and $30°p$ for semidiurnals.

Hence (62), quoted above, shows us that, for diurnal tides, the sum of all the entries (of which suppose there are q) in the column numbered p-hours, is

$$\cos 15^\circ p\{A_1 q + A_2\Big[\cos(n_1-n_2)\frac{15p}{n_1} + \cos[(n_1-n_2)\Big(\frac{2\pi}{n_1}+\frac{15p}{n_1}\Big)]$$
$$+\cos[(n_1-n_2)\Big(2\frac{2\pi}{n_1}+\frac{15p}{n_1}\Big)] + \ldots\Big] + B_2[\&c.]\} + \sin 15^\circ p\ \{\&c.\} \quad (a)$$

And for semidiurnal tides the arguments of all the circular functions in (a) are to be doubled.

Now, we want to choose such a number of terms that the series by which A_2 and B_2 are multiplied may vanish. This is the case if the series is exactly re-entrant, and is nearly the case if nearly re-entrant.

The condition is exactly satisfied for diurnal tides, if

$$(n_1-n_2)q\frac{2\pi}{n_1}=2\pi r,$$

where r is either a positive or negative integer. And for semidiurnal tides, if

$$(n_1-n_2)q\frac{4\pi}{n_1}=2\pi r.$$

That is to say,

$$(n_1-n_2)q=n_1 r, \text{ for diurnal tides,}$$

or

$$(n_1-n_2)q=\tfrac{1}{2}n_1 r, \text{ for semidiurnal tides.}$$

It is not worth while attempting to eliminate the effect of the semidiurnal tides on the diurnal tides, and *vice versâ*, because we cannot be more than a fraction of a day out, and on account of the incommensurability of the speeds we cannot help being wrong to that amount.

S *Series.*

Now suppose we are analysing for the S_2 tide, and wish to minimise the effect of the M_2 tide.

Then
$$n_1=2(\gamma-\eta)=2\times 15^\circ \text{ per hour,}$$
$$n_2=2(\gamma-\sigma),$$
$$n_1-n_2=2(\sigma-\eta)=1^\circ{\cdot}0158958 \text{ per hour.}$$

The equation is

$$1^\circ{\cdot}0158958q=15^\circ r.$$

If $r=25$, $q=369{\cdot}13$.

Thus 25 periods of $2(\sigma-\eta)$ is $369{\cdot}13$ mean solar days. It follows, therefore, that we must sum the series over 369 days in order to be as near right as possible.

Now this is equally true of all the columns, and each should have 369 entries.

Hence, in order to have 369 entries in each column, the present S_2 computation form should have the last three entries cut off. The divisors are to be, of course, changed accordingly.

M *Series.*

Now consider that we are analysing for M_2, and wish to minimise the effect of the S_2 tide. Hence

$$n_1=2(\gamma-\sigma)=2\times 14^\circ{\cdot}4920521 \text{ per hour},$$
$$n_2=2(\gamma-\eta),$$
$$n_1-n_2=-1^\circ{\cdot}0158958 \text{ per hour}.$$

Hence, taking r negative, the equation is

$$1^\circ{\cdot}0158958q=14^\circ{\cdot}4920521r.$$

If $r=25$, $q=356{\cdot}63$.

Thus 25 periods of $2(\sigma-\eta)$ is 356·63 of mean lunar time.

It follows, therefore, that we must have 357 entries in each column.

Thus the M_2 computation form should have the row numbered 357 complete, adding 9 more entries.

There are no 'changes' amongst these 9 entries. The divisors are to be modified accordingly, here and in all subsequent cases.

K *Series.*

To minimise the effect of M_2 on K_2, we have

$$n_1=2\gamma=2\times 15^\circ{\cdot}0410686 \text{ per hour},$$
$$n_2=2(\gamma-\sigma),$$
$$n_1-n_2=2(\sigma-\eta)=1^\circ{\cdot}0158958 \text{ per hour}.$$
$$1^\circ{\cdot}0158958q=15^\circ{\cdot}0410686r.$$

If $r=25$, $q=370{\cdot}14$.

Hence we should complete the row numbered 370.

The last 3 entries of the existing tables are to be cut off.

To minimise the effect of O on K_1, we have

$$n_1=\gamma=15^\circ{\cdot}0410686 \text{ per hour},$$
$$n_2=\gamma-2\sigma,$$
$$n_1-n_2=2\sigma=1^\circ{\cdot}0980330 \text{ per hour}.$$
$$1^\circ{\cdot}0980330q=15^\circ{\cdot}0410686r.$$

If $r=27$, $q=369{\cdot}85$.

Thus $q=370$ again gives the best result, and confirms the conclusion from the above.

The N *Series.*

Here $$n_1=2\gamma-3\sigma+\varpi=2\times 14^\circ{\cdot}2198648 \text{ per hour}.$$

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$
$$n_1-n_2=(\sigma-\varpi)=-0^\circ{\cdot}5443747 \text{ per hour}.$$
$$0{\cdot}5443747q=14^\circ{\cdot}2198648r.$$

If $r=13$, $q=339{\cdot}58$.

Hence we should complete the row numbered 340.

There is no justification for the alternative offered in the computation forms of continuing the entries up to $369^{\mathrm{d}}\ 3^{\mathrm{h}}$ of mean solar time.

The L *Series.*

Here $$n_1=2\gamma-\sigma-\varpi=2\times 14^\circ{\cdot}7642394 \text{ per hour}.$$

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$
$$n_1-n_2=\sigma-\varpi=0^\circ{\cdot}5443747 \text{ per hour.}$$
$$0{\cdot}5443747q=14^\circ{\cdot}7642394r.$$

If $r=13$, $q=352{\cdot}58$.

Hence we should complete the row numbered 353.

There is no justification for the alternative offered in the computation forms of continuing the entries up to $369^d\ 3^h$ of mean solar time.

The ν Series.

Here $\quad n_1=2\gamma-3\sigma-\varpi+2\eta=2\times14^\circ{\cdot}2562915$ per hour.

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$
$$n_1-n_2=-\sigma-\varpi+2\eta=-0^\circ{\cdot}4715211 \text{ per hour.}$$
$$0{\cdot}4715211q=14{\cdot}2562915r.$$

If $r=11$, $q=332{\cdot}6$.

Hence we should complete the row numbered 333.

There is no justification for the alternative offered in the computation forms of continuing the entries up to $369^d\ 3^h$ of mean solar time.

The λ Series.

Here $\quad n_1=2\gamma-\sigma+\varpi-2\eta=2\times14^\circ{\cdot}7278127$ per hour.

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$
$$n_1-n_2=\sigma+\varpi-2\eta=0^\circ{\cdot}4715211 \text{ per hour.}$$
$$0{\cdot}4715211q=14{\cdot}7278127r.$$

If $r=11$, $q=343{\cdot}58$.

Hence we should complete the row numbered 344.

There is no justification for the alternative offered in the computation forms of continuing the entries up to $369^d\ 3^h$ of mean solar time.

The 2N Series.

Here $\quad n_1=2\gamma-4\sigma+2\varpi=2\times13^\circ{\cdot}9476774$ per hour.

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$
$$n_1-n_2=-2(\sigma-\varpi)=1^\circ{\cdot}0887494 \text{ per hour.}$$
$$1{\cdot}0887494q=13{\cdot}9476774r.$$

If $r=26$, $q=333{\cdot}08$.

Hence we must complete the row numbered 333.

The T Series.

Here $\quad n_1=2\gamma-3\eta=2\times14^\circ{\cdot}9794657$ per hour.

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$
$$n_1-n_2=2\sigma-3\eta=0^\circ{\cdot}9748272 \text{ per hour.}$$
$$0{\cdot}9748272q=14{\cdot}9794657r.$$

If $r=24$, $q=368{\cdot}79$.

Hence we must complete the row numbered 369.

The R *Series.*

Here $n_1=2\gamma-\eta=2\times15°\cdot0205343$ per hour.

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$

$$n_1-n_2=2\sigma-\eta=1°\cdot0569644 \text{ per hour.}$$

$$1\cdot0569644q=15\cdot0205343r.$$

If $r=25$, $q=355\cdot28$, and $r=26$, $q=369\cdot49$.

Hence we should either complete the row numbered 355 or that numbered 369.

The 2MS *Series.*

Here $n_1=2\gamma-4\sigma+2\eta=2\times13°\cdot9841042$ per hour.

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$

$$n_1-n_2=-2(\sigma-\eta)=-1°\cdot0158958 \text{ per hour.}$$

$$1\cdot0158958q=13\cdot9841042r.$$

If $r=24$, $q=330\cdot37$, and $r=25$, $q=344\cdot13$.

Hence we should either complete the row numbered 330 or that numbered 344.

The 2SM *Series.*

Here $n_1=2\gamma+2\sigma-4\eta=2\times15°\cdot5079479$ per hour.

To minimise the effect of M_2,

$$n_2=2\gamma-2\sigma,$$

$$n_1-n_2=4(\sigma-\eta)=2°\cdot0317916 \text{ per hour.}$$

$$2\cdot0317916q=15\cdot5079479r.$$

If $r=48$, $q=366\cdot37$.

Hence we should complete the row numbered 366.

The O *Series.*

Here $n_1=\gamma-2\sigma=13°\cdot9430356$ per hour.

To minimise the effect of K_1,

$$n_2=\gamma,$$

$$n_1-n_2=-2\sigma=-1°\cdot0980330 \text{ per hour.}$$

$$1\cdot0980330q=13\cdot9430356r.$$

If $r=27$, $q=342\cdot85$.

Hence we should complete the row numbered 343, cutting off the last three entries in the present forms.

The P *Series.*

Here $n_1=\gamma-2\eta=14°\cdot9589314$ per hour.

It is open to question whether it is best to minimise the effect of K_1 or of O.

For K_1 take $$n_2=\gamma,$$
$$n_1-n_2=-2\eta=-0^\circ{\cdot}0821372 \text{ per hour.}$$
$$0{\cdot}0821372q=14{\cdot}9589314r.$$
If $r=2$, $q=364{\cdot}24$.

Hence we should complete the row numbered 364.

For O, take $$n_2=\gamma-2\sigma,$$
$$n_1-n_2=2(\sigma-\eta)=1^\circ{\cdot}0158958 \text{ per hour.}$$
$$1{\cdot}0158958q=14{\cdot}9589314r.$$
If $r=25$, $q=368{\cdot}12$.

Hence we should complete the row numbered 368.

It is better to abide by this, for in the former case n_1-n_2 varies very slowly; and we may be satisfied that on stopping with row 368 the effects of O and K_1 will both be adequately eliminated.

The J Series.

Here $$n_1=\gamma+\sigma-\varpi=15^\circ{\cdot}5854433 \text{ per hour.}$$
To minimise the effect of K_1,
$$n_2=\gamma,$$
$$n_1-n_2=\sigma-\varpi=0^\circ{\cdot}5443747 \text{ per hour.}$$
$$0{\cdot}5443747q=15{\cdot}5854433r.$$
If $r=12$, $q=343{\cdot}56$, and $r=13$, $q=372{\cdot}19$.

To minimise the effect of O,
$$n_2=\gamma-2\sigma,$$
$$n_1-n_2=3\sigma-\varpi=1^\circ{\cdot}6424077 \text{ per hour.}$$
$$1{\cdot}6424077q=15{\cdot}5854433r.$$
If $r=36$, $q=341{\cdot}6$, and $r=39$, $q=370{\cdot}09$.

Since in the latter case n_1-n_2 varies three times as fast as in the former, it will be better to abide by this, and stop either with the row numbered 342 or that numbered 370.

The Q Series.

Here $$n_1=\gamma-3\sigma+\varpi=13^\circ{\cdot}3986609 \text{ per hour.}$$
To minimise the effect of K_1,
$$n_2=\gamma,$$
$$n_1-n_2=-(3\sigma-\varpi)=-1^\circ{\cdot}6424077 \text{ per hour.}$$
$$1{\cdot}6424077q=13{\cdot}3986609r.$$
If $r=38$, $q=310{\cdot}00$.

To minimise the effect of O,
$$n_2=\gamma-2\sigma,$$
$$n_1-n_2=-(\sigma-\varpi)=-0^\circ{\cdot}5443747 \text{ per hour.}$$
$$0{\cdot}5443747q=13{\cdot}3986609r.$$
If $r=12$, $q=307{\cdot}36$.

Since in the former case n_1-n_2 varies about three times as fast as in

the latter, it will be better to abide by the former, and stop with the row numbered 310.

With regard to the quaterdiurnal and terdiurnal tides, it does not signify where we stop; but it seems more reasonable to stop with the exact year of 365 mean solar days. These tides are called MS, MN, MK, 2MK.

Schedule II.

Periods over which the Harmonic Analysis should extend.

Initial of series	Number of day and hour of last entry in special time	Period elapsing from 0^h of special day 1 to 23^h of last special day in mean solar hours
S	369^d 23^h	368^d 23^h
M	357 23	369 11
K	370 23	368 23
N	340 23	358 15
L	353 23	358 14
ν	333 23	350 8
λ	344 23	350 8
2N	333 23	358 2
T	369 23	369 11
R	355 23 or 370 23	354 11 or 369 11
2MS	330 23 or 344 23	353 22 or 368 23
2SM	366 23	353 23
O	343 23	368 23
P	368 23	368 23
J	342 23 or 370 23	329 3 or 356 1
Q	310 23	347 0

In the second column the numbers are given to the nearest mean solar hour.

IV. A Comparison of the Harmonic Treatment of Tidal Observations with the Older Methods.

§ 1. *On the Method of Computing Tide-tables.*

There is nothing in the harmonic reduction of tidal observations which necessitates recourse to mechanical prediction of the tides. It may happen that it is desirable to produce a tide-table by arithmetical processes, and that the computers prefer to use the older methods of corrections, or it may be desired to obtain the tidal constants in the harmonic notation from older observations. For either of these purposes it is necessary to show how the harmonically expressed results may be converted into the older form, so that the constants for the fortnightly inequality in time and height, and the corrections for parallax and declination, may be obtained from those of the harmonic analysis, and conversely.

In the following sections I propose, therefore, first to reduce the harmonic presentment of the resultant tide into the synthetic form, where we have a single harmonic term depending on the local mean solar time of moon's transit, and on corrections depending on the R.A., declination, and parallax of the perturbing bodies. Subsequently it will be shown how a synthesis may be carried out more simply by retaining the mean longitudes and elements of the orbits.

§ 2. *Notation for Mean Heights and Retardations derived from the Harmonic Method.*

The notation of the Report of 1883 is adopted; and I shall carry the approximation to about the same degree as has been adopted by the older writers. Closer approximation may, of course, be easily obtained.

In the Report of 1883 the mean height[1] of a tide is denoted by H, and the retardation or lag by κ. In the present note it will be necessary to refer to several of the H's and κ's at the same time, and therefore it is expedient to introduce the following notation:—

Schedule III.

Initial of tide	Mean height (H)	Retardation (κ)	Initial of tide	Mean height (H)	Retardation (κ)
M_2	M	2μ	L	L	2λ
S_2	S	2ζ	T	T	2ζ
Lunar K_2	K''	2κ	R	R	2ζ
Solar K_2	$K_{\prime}''$	2κ	O	M'	μ'
K_2	K_2	2κ	P	S'	ζ'
N	N	2ν	K_1	K_1	κ_1

In this schedule we assume T and R (of speeds $2\gamma-3\eta$ and $2\gamma-\eta$) to have the same lag as S_2; and we use ν in a new sense, the old ν, the

[1] I use height to denote semi-range. All references to this Report will simply be by the date 1883.

R.A. of the intersection of the equator with the lunar orbit, being denoted by ν_0. The initials of each tide are used to denote its height at any time.

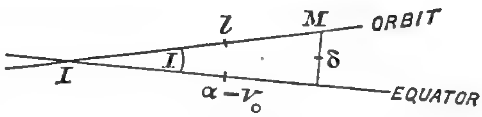
§ 3. *Introduction of Hour-angles, Parallaxes, and Declinations.*

We must now get rid of the elements of the orbit and of the mean longitudes, and introduce hour-angles, declinations, and parallaxes.

At the time t let α, δ, ψ be ☽'s R.A., and declination, and hour-angle.
and $\alpha_{\prime\prime}$, $\delta_{\prime\prime}$, $\psi_{\prime\prime}$, ☉'s R.A., and declination, and hour-angle.

Let l be ☽'s longitude in her orbit measured from 'the intersection,' and $\alpha-\nu_0$ (ν_0 being the ν of 1883) be ☽'s R.A. measured from the intersection.

The annexed figure exhibits the relation of the several angles to one another.



The spherical triangle affords the relations

$$\tan(\alpha-\nu_0)=\cos I\tan l,\quad \sin\delta=\sin I\sin l \quad . \quad . \quad . \quad . \quad (1)$$

From the first of (1) we have, approximately,

$$\alpha=l+\nu_0-\tan^2\tfrac{1}{2}I\sin 2l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Now, $s-\xi$ is the moon's mean longitude measured from I, and $s-p$ is the mean anomaly. Hence, approximately,

$$l=s-\xi+2e\sin(s-p) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

And therefore, approximately,

$$\alpha=s+\nu_0-\xi+2e\sin(s-p)-\tan^2\tfrac{1}{2}I\sin 2(s-\xi) \quad . \quad . \quad . \quad (4)$$

Now, $t+h$ being the sidereal hour-angle,

$$\psi=t+h-\alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Therefore, from (4) and (5),

$$t+h-s-(\nu_0-\xi)=\psi+2e\sin(s-p)-\tan^2\tfrac{1}{2}I\sin 2(s-\xi). \quad . \quad (6)$$

By the second of (1) we have, approximately,

$$\cos^2\delta=1-\tfrac{1}{2}\sin^2 I+\tfrac{1}{2}\sin^2 I\cos 2(s-\xi) \quad . \quad . \quad . \quad . \quad (7)$$

Hence, if Δ be such a declination that $\cos^2\Delta$ is the mean value of $\cos^2\delta$, we have

$$\left.\begin{aligned}\cos^2\Delta&=1-\tfrac{1}{2}\sin^2 I\\ \text{and }\cos^2\Delta_{\prime}&=1-\tfrac{1}{2}\sin^2\omega\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

From this we have (neglecting terms in $\sin^4\Delta$) the following relations:—

$$\cos^4\tfrac{1}{2}I=\cos^2\Delta,\quad \sin I\cos^2\tfrac{1}{2}I=\sqrt{2}\sin\Delta\cos\Delta,\quad \sin^2 I=2\sin^2\Delta,$$

$$\cos^4\tfrac{1}{2}\omega=\cos^2\Delta_{\prime},\quad \sin\omega\cos^2\tfrac{1}{2}\omega=\sqrt{2}\sin\omega\cos\omega,\quad \sin^2\omega=2\sin^2\Delta_{\prime}.$$

Thus we may put

$$\left.\begin{aligned} &\frac{\cos^4\frac{1}{2}I}{\cos^4\frac{1}{2}\omega\cos^4\frac{1}{2}i}=\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}, \qquad \frac{\sin I\cos^2\frac{1}{2}I}{\sin\omega\cos^2\frac{1}{2}\omega\cos^4\frac{1}{2}i}=\frac{\sin 2\Delta}{\sin 2\Delta_{\prime}} \\ &\frac{\sin^2 I}{\sin^2\omega(1-\frac{3}{2}\sin^2 i)}=\frac{\sin^2\Delta}{\sin^2\Delta_{\prime}}, \quad \tan^2\tfrac{1}{2}I=\tfrac{1}{2}\tan^2\Delta \end{aligned}\right\} \quad . \quad . \quad (9)$$

An approximate formula for Δ and the value of $\Delta_{\prime}$ are

$$\Delta=16^{\circ}\cdot 51+3^{\circ}\cdot 44\cos\mathrm{N}-0^{\circ}\cdot 19\cos 2\mathrm{N},\ \Delta_{\prime}=16^{\circ}\cdot 36 \quad . \quad . \quad (10)$$

The introduction of Δ and $\Delta_{\prime}$ in place of I and ω entails a loss of accuracy, and it is only here made because former writers have followed that plan. It may easily be dispensed with.

Now let us write

$$\left.\begin{aligned} D&=\cos 2(s-\xi), \qquad D'=\sin 2(s-\xi) \\ \Pi&=\cos(s-p), \qquad \Pi'=\sin(s-p) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (11)$$

From (7) and (8),

$$D=\frac{\cos^2\delta-\cos^2\Delta}{\sin^2\Delta}, \qquad D'=\frac{\sin\delta\cos\delta}{\sigma\sin^2\Delta}\frac{d\delta}{dt} \quad . \quad . \quad . \quad . \quad (12)$$

Then, if we write for the ratio of the moon's parallax to her mean parallax P, we have

$$P-1=e\cos(s-p),$$

and

$$\Pi=\frac{1}{e}(P-1), \qquad \Pi'=-\frac{1}{e(\sigma-\varpi)}\frac{dP}{dt} \quad . \quad . \quad . \quad . \quad (13)$$

Hence D, D', Π, Π' are functions of declinations and parallaxes. The similar symbols with subscript accents are to apply to the sun.

Now (6) may be written by aid of (9) and (11),

$$2[t+h-s-(\nu_{\circ}-\xi)]=2\psi+4e\Pi'-D'\tan^2\Delta \quad . \quad . \quad . \quad (14)$$

The left-hand side of (14) is the argument of M_2 (see Sched. B. i. 1883), and from (9) the factor of M_2 is $\cos^2\Delta/\cos^2\Delta_{\prime}$. Hence, subtracting the retardation 2μ from (14) we have

$$(M_2)=\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}M\cos[(2\psi+4e\Pi'-D'\tan^2\Delta)-2\mu],$$

expanding approximately,

$$\begin{aligned} (M_2)=&\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}M\cos 2(\psi-\mu) \\ &-\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}\Pi' 4Me\sin 2(\psi-\mu) \\ &+\frac{\sin^2\Delta}{\cos^2\Delta_{\prime}}D'M\sin 2(\psi-\mu) \quad . \quad . \quad . \quad . \quad . \quad . (15) \end{aligned}$$

We shall see later that the two latter terms of (15) are nearly annulled by terms arising from other tides, and as in the case of the sun the rates of change of parallax and declination are small, we may write by symmetry,

$$(S_2)=S\cos 2(\psi_{\prime}-\zeta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

In all the smaller tides we may write

$$t+h-s-(\nu_{\circ}-\xi)=\psi.$$

A general formula of transformation will be required below. Thus, if $\cos 2x=X$, $\sin 2x=X'$,

$$\cos 2(\psi\mp x-\alpha)=(X\mp\tan 2(\alpha-\mu)X')\cos 2(\psi-\alpha)$$
$$\pm\frac{X'}{\cos 2(\alpha-\mu)}\sin 2(\psi-\mu) \quad . \quad (17)$$

The lunar K_2 *tide.*

From Sched. B. i., 1883, we have

$$\text{Lunar } K_2=\frac{\sin^2 I}{\sin^2\omega(1-\frac{3}{2}\sin^2 i)}K''\cos 2[t+h-\nu_{\circ}-\kappa]$$
$$=\frac{\sin^2\Delta}{\sin^2\Delta_{\prime}}K''\cos 2[\psi+(s-\xi)-\kappa].$$

Applying (17) with $X=D$, $X'=D'$, $\alpha=\kappa$, and taking the lower sign,

$$\text{Lunar } K_2=\frac{\sin^2\Delta}{\sin^2\Delta_{\prime}}K''\Big[(D+\tan 2(\kappa-\mu)D')\cos 2(\psi-\kappa)$$
$$-\frac{D'}{\cos 2(\kappa-\mu)}\sin 2(\psi-\mu)\Big]. \quad . \quad . \quad (18)$$

In the case of the sun we neglect the terms in D', for the same reasons as were assigned for the similar neglect in (16), and have

$$\text{Solar } K_2=K_{\prime}''D_{\prime}\cos 2(\psi_{\prime}-\kappa) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

The tide N.

From Schedule B. i., Report 1883,

$$(\text{N})=\frac{\cos^4\frac{1}{2}I}{\cos^4\frac{1}{2}\omega\cos^4\frac{1}{2}i}N\cos[2(t+h-s-\nu_{\circ}+\xi)-(s-p)-2\nu].$$

Then $$(\text{N})=\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}N\cos 2[\psi-\nu-\tfrac{1}{2}(s-p)].$$

Then applying (17) with $X=\Pi$, $X'=\Pi'$, $\alpha=\nu$, and taking the upper sign, but writing $\mu-\nu$ instead of $\nu-\mu$, because this tide being slower than M_2 suffers less retardation,

$$(\text{N})=\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}N\Big[(\Pi+\tan 2(\mu-\nu)\Pi')\cos 2(\psi-\nu)$$
$$+\frac{\Pi'}{\cos 2(\mu-\nu)}\sin 2(\psi-\mu)\Big] \quad (20)$$

The tide L.

We shall here omit the small tide of speed $2\gamma-\sigma+\varpi$, by which the true elliptic tide is perturbed. Thus the R in the column of arguments in Sched. B. i., 1883, is neglected, and we have

$$(\text{L})=-\frac{\cos^4\frac{1}{2}I}{\cos^4\frac{1}{2}\omega\cos^4\frac{1}{2}i}L\cos[2(t+h-s-\nu+\xi)+(s-p)-2\lambda]$$
$$=-\frac{\cos^2\Delta}{\cos\Delta_{\prime}}L\cos 2[\psi-\lambda+\tfrac{1}{2}(s-p)].$$

Applying (17) with $X=\Pi$, $X'=\Pi'$, $a=\lambda$, and taking the lower sign, and changing the sign of the whole, because of the initial negative sign,

$$(\mathrm{L})=\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}L\Big[(-\Pi-\tan 2(\lambda-\mu)\Pi')\cos 2(\psi-\lambda)$$
$$+\frac{\Pi'}{\cos 2(\lambda-\mu)}\sin 2(\psi-\mu)\Big]. \quad (21)$$

The sum of N *and* L.

In order to fuse these terms an approximation will be adopted. The L tide is just as much faster than M_2 as N is slower, but the N tide should be nearly 7 times as great as the L tide; hence the $\tan 2(\lambda-\mu)$ in (21) will be put equal to $\tan 2(\mu-\nu)$. We then have

$$(\mathrm{N})+(\mathrm{L})=\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}\Big[(\Pi+\tan 2(\mu-\nu)\Pi')(N\cos 2(\psi-\nu)-L\cos 2(\psi-\lambda))$$
$$+\Pi'(N\sec 2(\mu-\nu)+L\sec 2(\lambda-\mu))\sin 2(\psi-\mu)\Big].$$

But

$$N\cos 2(\psi-\nu)-L\cos 2(\psi-\lambda)=\cos 2\psi(N\cos 2\nu-L\cos 2\lambda)$$
$$+\sin 2\psi(N\sin 2\nu-L\sin 2\lambda).$$

Then writing

$$\tan 2\epsilon=\frac{N\sin 2\nu-L\sin 2\lambda}{N\cos 2\nu-L\cos 2\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

so that ϵ is nearly equal to ν, we have

$$(\mathrm{N})+(\mathrm{L})=\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}\,\frac{N\cos 2\nu-L\cos 2\lambda}{\cos 2\epsilon}\Big[(\Pi+\tan 2(\mu-\nu)\Pi')\cos 2(\psi-\epsilon)\Big]$$
$$+\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}\Big[(N\sec 2(\mu-\nu)+L\sec 2(\lambda-\mu))\sin 2(\psi-\mu)\Big] \quad . \quad (23)$$

In the symmetrical term for the sun, with approximation as in (16), we get

$$(\mathrm{T})+(\mathrm{R})=(T-R)\,\Pi_{\prime}\cos 2(\psi_{\prime}-\zeta) \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

This terminates the semidiurnal tides which we are considering; but before proceeding to collect the results some further transformations must be exhibited.

Let us consider the function $D+xD'$, where x is small. From (12) we see that

$$D+xD'=\frac{\cos^2\delta-\cos^2\Delta}{\sin^2\Delta}+\tfrac{1}{2}x\frac{2\sin\delta\cos\delta}{\sigma\sin^2\Delta}\,\frac{d\delta}{dt}.$$

Hence, if δ' be the moon's declination at a time earlier than the time of observation by $x/2\sigma$, then

$$D+xD'=\frac{\cos^2\delta'-\cos^2\Delta}{\sin^2\Delta}.$$

Hence, in (17),

$$D+\tan 2(\kappa-\mu)D'=\frac{\cos^2\delta'-\cos^2\Delta}{\sin^2\Delta} \quad . \quad . \quad . \quad . \quad . \quad (25)$$

when δ' is the moon's declination at time $\frac{1}{15}t-57^\circ{\cdot}3\tan 2(\kappa-\mu)/2\sigma$. The period $57^\circ{\cdot}3\tan 2(\kappa-\mu)/2\sigma$ may be called 'the age of the declinational inequality.'

Again,

$$\Pi+x\Pi'=\frac{1}{e}\left\{P-1-\frac{x}{\sigma-\varpi}\frac{dP}{dt}\right\}.$$

Hence, if $(P'-1)/e$ denotes the value of $(P-1)/e$ at a time $x/(\sigma-\varpi)$ earlier than that of observation, then

$$\Pi+x\Pi'=\frac{1}{e}(P'-1).$$

Hence, in (23),

$$\Pi+\tan 2(\mu-\nu)\Pi'=\frac{1}{e}(P'-1) \quad . \quad . \quad . \quad . \quad . \quad (26)$$

where P' is the ratio of the moon's parallax to her mean parallax at a time $\frac{1}{15}t-57^\circ\cdot3\tan 2(\mu-\nu)/(\sigma-\varpi)$. The period $57^\circ\cdot3\tan 2(\mu-\nu)/(\sigma-\varpi)$ may be called 'the age of the parallactic inequality.'

In collecting results we shall write the sum

$$\mathrm{M}_2+\mathrm{S}_2+\mathrm{K}_2+\mathrm{N}+\mathrm{L}+\mathrm{R}+\mathrm{T}=h_2.$$

For reasons explained below we omit terms depending on the rate of change of solar parallax and declination.

Then, from (15), (16), (18), (19), (23), (24), (25), (26), we have

$$\begin{aligned}
h_2=&\frac{\cos^2\Delta}{\cos^2\Delta_{,}}M\cos 2(\psi-\mu)+S\cos 2(\psi_{,}-\zeta)\\
&+\frac{\cos^2\delta'-\cos^2\Delta}{\sin^2\Delta_{,}}K''\cos 2(\psi-\kappa)+\frac{\cos^2\delta_{,}-\cos^2\Delta_{,}}{\sin^2\Delta_{,}}K_{,}''\cos 2(\psi_{,}-\kappa)\\
&-\frac{\sin\delta\cos\delta}{\sigma\sin^2\Delta_{,}}\frac{d\delta}{dt}\left(\frac{K''}{\cos 2(\kappa-\mu)}-M\tan^2\Delta_{,}\right)\sin 2(\psi-\mu)\\
&+\frac{\cos^2\Delta}{\cos^2\Delta_{,}}(P'-1)\frac{N\cos 2\nu-L\cos 2\lambda}{e\cos 2\epsilon}\cos 2(\psi-\epsilon)\\
&+(P_{,}-1)\frac{(T-R)}{e_{,}}\cos 2(\psi_{,}-\zeta)\\
&+\frac{\cos^2\Delta}{\cos^2\Delta_{,}}\frac{1}{\sigma-\varpi}\frac{dP}{dt}\left(4M-\frac{N\sec 2(\mu-\nu)+L\sec 2(\lambda-\mu)}{e}\right)\sin 2(\psi-\mu)
\end{aligned}\qquad (27)$$

It may easily be shown, from Schedule B. i., 1883, that in the equilibrium theory $K''-M\tan^2\Delta_{,}=0$, and $4M-(N+L)/e=0$; hence the terms depending on rates of change of declination and parallax are small. This also shows that we were justified in neglecting the corresponding terms in the case of the sun. Also, since the faster tides are more augmented by kinetic action than the slow ones, the two functions, written above, which vanish in the equilibrium theory are normally actually positive. The formula (27) gives the complete expression for the semidiurnal tide in terms of hour-angles, declinations, and parallaxes, with the constants of the harmonic analysis.

We shall now show that with rougher approximation (27) is reducible to a much simpler form.

The retardation of each tide should be approximately a constant, plus

a term varying with the speed. Hence all the retardations may be expressed in terms of ζ and μ, and

$$\kappa=\mu+\frac{\zeta-\mu}{\sigma-\eta}\sigma,$$

$$\nu=\mu-\frac{\zeta-\mu}{\sigma-\eta}\tfrac{1}{2}(\sigma-\varpi),$$

$$\lambda=\mu+\frac{\zeta-\mu}{\sigma-\eta}\tfrac{1}{2}(\sigma-\varpi).$$

It is clear that κ differs very little from ζ, and that

$$\frac{\kappa-\mu}{\sigma}=\frac{2(\mu-\nu)}{\sigma-\varpi}=\frac{\zeta-\mu}{\sigma-\eta}.$$

The time $(\zeta-\mu)/(\sigma-\eta)$ is called 'the age of the tide,' for reasons explained below, and $\kappa-\mu$, $\mu-\nu$, not being large angles, do not differ much from these tangents. Hence the ages of the declinational and parallactic inequalities are both approximately equal to the age of the tide.

Let æ, then, denote $(\zeta-\mu)/(\sigma-\eta)$, the age of the tide.

Now, as an approximation, we may suppose that heights of the lunar K_2 tide, the N and L tides bear the same ratio to the M_2 tide as in the equilibrium theory; and that the solar K_2, the T and R tides bear the same ratio to the S_2 tide as in that theory. Then reverting to the notation with I, ω, i in place of $\triangle$, $\triangle_{,,}$ and writing

$$\left(\frac{\cos\frac{1}{2}I}{\cos\frac{1}{2}\omega\cos\frac{1}{2}i}\right)^4=\text{f},$$

we have

$$\frac{\sin^2\triangle}{\sin^2\triangle_{,}}K''=\frac{\frac{1}{2}\sin^2 I}{\cos^4\frac{1}{2}I}\,\text{f}M,\quad \frac{\cos^2\triangle}{\cos^2\triangle_{,}}N=\tfrac{7}{2}e\text{f}M,\quad \frac{\cos^2\triangle}{\cos^2\triangle_{,}}L=\tfrac{1}{2}e\text{f}M,$$

$$K_{,}''=\frac{\frac{1}{2}\sin^2\omega}{\cos^4\frac{1}{2}\omega}S,\ T=\tfrac{7}{2}e_{,}S,\ R=\tfrac{1}{2}e_{,}S.$$

Also, since (22) may be written

$$\tan(2\mu-2\varepsilon)=\frac{N\sin 2(\mu-\nu)+L\sin 2(\lambda-\mu)}{N\cos 2(\mu-\nu)-L\cos 2(\lambda-\mu)},$$

we have, treating $\mu-\nu$, $\lambda-\mu$, $\mu-\varepsilon$ as small, approximately,

$$\varepsilon=\mu-\tfrac{2}{3}\text{æ}(\sigma-\varpi)=\mu-\tfrac{2}{3}(\lambda-\nu).$$

Also

$$\frac{\cos^2\triangle}{\cos^2\triangle_{,}}\,\frac{N\cos 2\nu-L\cos 2\lambda}{\cos 2\varepsilon}=3e\text{f}M.$$

Then reverting to mean longitudes, and substituting the age of tide where required, we find, on neglecting the difference between κ and ζ,

For the lunar declinational term,

$$2\tan^2\tfrac{1}{2}I\,\text{f}M\cos 2[s-\text{æ}\sigma-\xi]\cos 2(\psi-\zeta);$$

For the solar declinational term,

$$2\tan^2\tfrac{1}{2}\omega\,S\cos 2h\cos 2(\psi_{,}-\zeta);$$

For the lunar parallactic term,

$$3e\text{f}M\cos[s-p-\text{æ}(\sigma-\varpi)]\cos 2[\psi-\mu+\tfrac{2}{3}\text{æ}(\sigma-\varpi)];$$

For the solar parallactic term,

$$3e_{\prime}S\cos(h-p_{\prime})\cos 2[\psi_{\prime}-\zeta].$$

Then omitting the terms depending on changes of declination and parallax, we have as an approximation,

$$h_2=\mathrm{f}M\Big[\cos 2(\psi-\mu)+2\tan^2\tfrac{1}{2}I\cos 2[s-x\sigma-\xi]\cos 2(\psi-\zeta)$$
$$+3e\cos[s-p-x(\sigma-\varpi)]\cos 2[\psi-\mu+\tfrac{2}{3}x(\sigma-\varpi)]\Big]$$
$$+S\Big[1+2\tan^2\tfrac{1}{2}\omega\cos 2h+3e_{\prime}\cos(h-p_{\prime})\Big]\cos 2(\psi_{\prime}-\zeta)\quad . \quad . \quad (28)$$

In the equilibrium theory we have the lunar semidiurnal tide depending on $r^{-3}\cos^2\delta\cos 2\psi$. Now it is obvious that $\cos^2\delta$ introduces a factor $1+2\tan^2\frac{1}{2}I\cos 2(s-\xi)$, and r^{-3} a factor $1+3e\cos(s-p)$. Thus, if we could have foreseen the exact disturbance introduced by friction and other causes in the various angles, the formula (28) might have been established at once; but it seems to have been necessary to have recourse to the complete development in order to find how the age of the tide will enter.

§ 4. *Reference to Time of Moon's Transit.*

It has been usual to refer the tide to the time of moon's transit, and we shall now proceed to the transformations necessary to do so.

$\cos^2\triangle/\cos^2\triangle_{\prime}$ goes through its oscillation about the value unity in 19 years; it is therefore convenient to write for, say, a whole year,

$$\left.\begin{aligned} M_{\circ}&=\frac{\cos^2\triangle}{\cos^2\triangle_{\prime}}M\\ \text{and similarly,}\quad N_{\circ}&=\frac{\cos^2\triangle}{\cos^2\triangle_{\prime}}N\\ L_{\circ}&=\frac{\cos^2\triangle}{\cos^2\triangle_{\prime}}L \end{aligned}\right\}\quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

We also observe that K'' and $K_{\prime}''$, being the lunar and solar parts of the mean K_2 tide, and their ratio being ·464 (Report, 1883),

$$K''=\cdot 68303\,K_2,\quad K_{\prime}''=\cdot 31697\,K_2\quad . \quad . \quad . \quad . \quad (30)$$

It will also be seen that in all the terms arising from the sun, excepting that in $K_{\prime}''$, the argument of the cosine is $2(\psi_{\prime}-\zeta)$. It will be convenient, and sufficiently accurate for all practical purposes, to replace κ by ζ in this solar declinational term $K_{\prime}''$.

We shall now proceed to refer the tide to the moon's transit at the place of observation.

Let $a_{\circ}$, $h_{\circ}$ be ☽'s R.A and ☉'s mean longitude at ☽'s transit—say upper transit, for distinctness. Then the local time of transit is given by the vanishing of ψ, and since $\psi=t+h-a$, it follows that the time-angle of ☽'s transit (at 15° to the hour) is $a_{\circ}-h_{\circ}$.

Now let τ (mean solar hours) be the interval after transit to which the time-angle t refers; then, since

$$\frac{dh}{dt}=\eta,\ \frac{da}{dt}=\sigma+\left(\frac{da}{dt}-\sigma\right),\ \gamma-\eta=15°,\ \gamma-\sigma=14°{\cdot}49,$$

$$\begin{aligned}\psi&=t+h-a\\&=[(\gamma-\eta)\tau+a_\circ-h_\circ]+[h_\circ+\eta\tau]-\left[a_\circ+\sigma\tau+\left(\frac{da}{dt}-\sigma\right)\tau\right],\end{aligned}$$

$$\psi=(\gamma-\sigma)\tau-\left(\frac{da}{dt}-\sigma\right)\tau.$$

For the sake of brevity, put

$$T=(\gamma-\sigma)\tau,$$

so that T is τ converted to angle at the rate of 14°·49 per hour. Then we have

$$\psi=T-\left(\frac{da}{dt}-\sigma\right)\tau \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

Similarly putting $a_{\prime}$ for ☉'s R.A. at ☽'s transit, we have

$$\begin{aligned}\psi_{\prime}&=t+h-a_{\prime}\\&=[(\gamma-\eta)\tau+a_\circ-h_\circ]+[h_\circ+\eta\tau]-\left[a_{\prime}+\sigma\tau-\left(\sigma-\frac{da_{\prime}}{dt}\right)\tau\right];\end{aligned}$$

so that

$$\psi_{\prime}=(\gamma-\sigma)\tau+a_\circ-a_{\prime}+\left(\sigma-\frac{da_{\prime}}{dt}\right)\tau.$$

Then let

$$A=a_\circ-a_{\prime}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)^*$$

So that A is the apparent time of ☽'s transit, reduced to angle at 15° per hour, and we have

$$\psi_{\prime}=T+A+\left(\sigma-\frac{da_{\prime}}{dt}\right)\tau \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

It is only in the two principal tides that we need regard the changes of R.A. since ☽'s transit, and in all the smaller terms we may simply put

$$\psi=T,\quad \psi_{\prime}=T+A.$$

The first pair of terms of (28) now become

$$M_\circ \cos 2\left[T-\left(\frac{da}{dt}-\sigma\right)\tau-\mu\right]+S\cos 2\left[T+A+\left(\sigma-\frac{da_{\prime}}{dt}\right)\tau-\zeta\right],$$

and these are equal to

$$M_\circ\cos 2(T-\mu)+S\cos 2(T+A-\zeta)$$

$$+\frac{2\pi}{180}\left(\frac{da}{dt}-\sigma\right)\tau M_\circ\sin 2(T-\mu)-\frac{2\pi}{180}\left(\sigma-\frac{da_{\prime}}{dt}\right)\tau S\sin 2[T+A-\zeta] \quad (34)$$

We may now collect together all the results, and write them in the form of a schedule.

* It would be better to put

$$A=a_\circ-a_{\prime}+\frac{\sigma-\eta}{\gamma-\sigma}\mu.$$

If this be used the correction (40) for ☉'s change of R.A. becomes small.

Semidiurnal Tides.—Schedule IV.

Description of Term	Coefficient	Periodic Factor
Principal lunar	$M_\circ$	$\times \cos 2(\mathrm{T}-\mu)$
Principal solar	$+S$	$\times \cos 2(\mathrm{T}+A-\zeta)$
☽ Change of R.A.	$+\frac{2\pi}{180}\left(\frac{d\alpha}{dt}-\sigma\right)\tau M_\circ$	$\times \sin 2(\mathrm{T}-\mu)$
⊙ Change of R.A.	$-\frac{2\pi}{180}\left(\sigma-\frac{d\alpha_{\prime}}{dt}\right)\tau S$	$\times \sin 2(\mathrm{T}+A-\zeta)$
☽ Declination	$+\frac{\cos^2\delta'-\cos^2\Delta}{\sin^2\Delta_{\prime}}\cdot 683\, K_2$	$\times \cos 2(\mathrm{T}-\kappa)$
⊙ Declination	$+\frac{\cos^2\delta_{\prime}-\cos^2\Delta_{\prime}}{\sin^2\Delta_{\prime}}\cdot 317\ K_2$	$\times \cos 2(\mathrm{T}+A-\zeta)$
☽ Change of declination . . .	$-\frac{\sin\delta\cos\delta}{\sigma\sin^2\Delta_{\prime}}\frac{d\delta}{dt}\left(\frac{\cdot 683\, K_2}{\cos 2(\kappa-\mu)}-M\tan^2\Delta_{\prime}\right)$ . . .	$\times \sin 2(\mathrm{T}-\mu)$
☽ Parallax.	$+(P'-1)\frac{N_\circ\cos 2\nu-L_\circ\cos 2\lambda}{e\cos 2\varepsilon}$	$\times \cos 2(\mathrm{T}-\varepsilon)$
⊙ Parallax	$+(P_{\prime}-1)\frac{T-R}{e_{\prime}}$	$\times \cos 2(\mathrm{T}+A-\zeta)$
☽ Change of parallax	$+\frac{1}{\sigma-\varpi}\frac{dP}{dt}\left(4M_\circ-\frac{N_\circ\sec 2(\mu-\nu)+L_\circ\sec 2(\lambda-\mu)}{e}\right)$	$\times \sin 2(\mathrm{T}-\mu)$.

Definition of symbols :—

α, δ, $\alpha_{\prime}$, $\delta_{\prime}$ ☽'s and ⊙'s R.A. and declination at moon's transit; $A=\alpha-\alpha_{\prime}$, apparent time of ☽'s transit at the port.

δ' ☽'s decl. at the time (generally earlier than transit) $\tau-\frac{57^{\circ}\cdot 3}{2\sigma}\tan 2(\kappa-\mu)$.

P, $P_{\prime}$ the ratio of ☽'s and ⊙'s parallax to mean parallaxes.

P' the ratio for ☽ at the time (generally earlier than transit) $\tau-\frac{57^{\circ}\cdot 3}{\sigma-\varpi}\tan 2(\mu-\nu)$.

τ the time elapsed since ☽'s transit in m.s. hours; T the same time reduced to angle at 14°·49 per hour.

Δ such a declination that $\cos^2\Delta$ is the mean value of $\cos^2\delta$; Δ has a 19-yearly period.

$\Delta_{\prime}$ such a declination that $\cos^2\Delta_{\prime}$ is the mean value of $\cos^2\delta_{\prime}$.

e, $e_{\prime}$ eccentricities of lunar and solar orbits; σ the ☽'s mean motion; ϖ the mean motion of the ☽'s perigee.

$$\frac{M_{\circ}}{M}=\frac{N_{\circ}}{N}=\frac{L_{\circ}}{L}=\frac{\cos^2\Delta}{\cos^2\Delta_{\prime}}.$$

M, S, K_2, N, L, T, R the mean semi-ranges H of the tides of those denominations in the harmonic method. The retardations found by harmonic analysis are 2μ for M_2, 2ζ for S_2, 2κ for K_2, 2ν for N, 2λ for L, and 2ζ for T and R.

Lastly $\tan 2\epsilon=\frac{N\sin 2\nu-L\sin 2\lambda}{N\cos 2\nu-L\cos 2\lambda}$, 2ϵ to be taken in the same quadrant as 2ν.

§ 5. *Synthesis of the Several Terms.*

Consider the two principal terms in Schedule IV.

$$M_{\circ}\cos 2(\mathrm{T}-\mu)+S\cos 2(\mathrm{T}+A-\zeta).$$

They may be written in the form

$$H\cos 2(\mathrm{T}-\phi),$$

where

$$H\cos 2(\mu-\phi)=M_{\circ}+S\cos 2(A-\zeta+\mu),$$
$$H\sin 2(\mu-\phi)=S\sin 2(A-\zeta+\mu).$$

If we compute ϕ corresponding to the time of moon's transit from the formula

$$\tan 2(\mu-\phi)=\frac{S\sin 2(A-\zeta+\mu)}{M_{\circ}+S\cos 2(A-\zeta+\mu)},$$

then ϕ reduced to time at the rate of 14°·49 per hour is the interval after moon's transit to high water, to a first approximation. The angle $\phi\pm 90^{\circ}$, similarly reduced, gives the low waters before and after the high water, and $\phi\pm 180^{\circ}$ gives another high water. The high waters and low waters are to be referred to the nearest transit of the moon.

The height or depression is given to a first approximation by

$$H=\sqrt{(M_{\circ}^2+S^2+2M_{\circ}S\cos 2\,(\mu-\phi))}.$$

This variability in the time and height of high water, due to variability of ϕ, is called the fortnightly or semi-menstrual inequality in the height and interval. The period $(\zeta-\mu)/(\sigma-\eta)$ is called 'the age of the tide,' because this is the mean period after new and full moon before the occurrence of spring tide.

§ 6. *Corrections.*

The smaller terms in Schedule IV. may be regarded as inequalities in the principal terms. They are of several types. Consider a term $B\cos 2(\mathrm{T}-\beta)$.

Then

$$B\cos 2(\mathrm{T}-\beta)=B\cos 2(\beta-\phi)\cos 2(\mathrm{T}-\phi)+B\sin 2(\beta-\phi)\sin 2(\mathrm{T}-\phi).$$

Hence the addition of such a term to $H\cos 2(\mathrm{T}-\phi)$ gives us $(H+\delta H)\cos 2(\mathrm{T}-\phi-\delta\phi)$, where

$$\delta H=B\cos 2(\beta-\phi),\ 2H\delta\phi=B\sin 2(\beta-\phi).\quad .\ .\ .\ .\quad (35)$$

Next consider a term $C\sin 2(\mathrm{T}-\mu)$. Putting $\beta=\mu+\frac{1}{4}\pi$, we have

$$\delta H=-C\sin 2(\mu-\phi),\ 2H\delta\phi=C\cos 2(\mu-\phi)\quad .\ .\ .\quad (36)$$

Next consider a term $E\cos 2(\mathrm{T}+A-\zeta)$. Putting $\beta=\zeta-A$, we have

$$\delta H=E\cos 2(A-\zeta+\phi),\ 2H\delta\phi=-E\sin 2(A-\zeta+\phi)\quad .\ .\quad (37)$$

Lastly, consider a term $F\sin 2(\mathrm{T}+A-\zeta)$. Putting $\beta=\zeta-A+\frac{1}{4}\pi$, we have

$$\delta H=F\sin 2(A-\zeta+\phi),\ 2H\delta\phi=F\cos 2(A-\zeta+\phi)\quad .\ .\quad (38)$$

In writing down the corrections we substitute $14{\cdot}49\delta t$ for $\delta\phi$, and introduce a factor so that the times may be given in mean solar hours and the angular velocities in degrees per hour.

Change of Moon's R.A., Sched. IV.

This is of type (36), and gives

$$\left.\begin{aligned}\delta H&=-\frac{2\pi}{180}\left(\frac{d\alpha}{dt}-\sigma\right)\tau M_\circ\sin 2(\mu-\phi)\\ \delta t&=1^{\mathrm{h}}{\cdot}977\frac{2\pi}{180}\left(\frac{d\alpha}{dt}-\sigma\right)\tau\frac{M_\circ}{H}\cos 2(\mu-\phi)\end{aligned}\right\}\quad .\ .\ .\ .\ .\quad (39)$$

This correction to the height is very small.

Change of Sun's R.A., Sched. IV.*

This is of type (38), and gives

$$\left.\begin{aligned}\delta H&=-\frac{2\pi}{180}\left(\sigma-\frac{d\alpha_{\prime}}{dt}\right)\tau S\sin 2(A-\zeta+\phi)\\ \delta t&=-1^{\mathrm{h}}{\cdot}977\frac{2\pi}{180}\left(\sigma-\frac{d\alpha_{\prime}}{dt}\right)\tau\frac{S}{H}\cos 2(A-\zeta+\phi)\end{aligned}\right\}\quad .\ .\quad (40)$$

* With the value of A suggested in footnote to (32) $(\sigma-d\alpha_{\prime}/dt)\tau$ becomes $[(\phi-\mu)\sigma-(\phi d\alpha_{\prime}/dt-\mu\eta)]/(\gamma-\sigma)$ at high water. This is obviously very small.

Moon's Declination, Sched. IV.

This is of type (35), and gives

$$\left.\begin{aligned}\delta H&=\frac{\cos^2\delta'-\cos^2\Delta}{\sin^2\Delta_{,}}\cdot 683K_2\cos 2(\kappa-\phi)\\ \delta t&=1^{\text{h}}\cdot 977\frac{\cos^2\delta'-\cos^2\Delta}{\sin^2\Delta_{,}}\cdot 683\frac{K_2}{H}\sin 2(\kappa-\phi)\end{aligned}\right\}\quad . \quad . \quad (41)$$

Sun's Declination, Sched. IV.

This is of type (37), and gives

$$\left.\begin{aligned}\delta H&=\frac{\cos^2\delta_{,}-\cos^2\Delta_{,}}{\sin^2\Delta_{,}}\cdot 317\,K_2\cos 2(A-\zeta+\phi)\\ \delta t&=-1^{\text{h}}\cdot 977\frac{\cos^2\delta_{,}-\cos^2\Delta_{,}}{\sin^2\Delta_{,}}\cdot 317\,\frac{K_2}{H}\sin 2(A-\zeta+\phi)\end{aligned}\right\}\quad . \quad . \quad (42)$$

Change of Moon's Declination, Sched. IV.

This is of type (36), and gives

$$\left.\begin{aligned}\delta H&=\frac{\sin\delta\cos\delta}{\sigma\sin^2\Delta_{,}}\;\frac{d\delta}{dt}\left(\frac{\cdot 683\,K_2}{\cos 2(\kappa-\mu)}-M\tan^2\Delta_{,}\right)\sin 2(\mu-\phi)\\ \delta t&=-1^{\text{h}}\cdot 977\frac{\sin\delta\cos\delta}{\sigma H\sin^2\Delta_{,}}\;\frac{d\delta}{dt}\left(\frac{\cdot 683\,K_2}{\cos 2(\kappa-\mu)}-M\tan^2\Delta_{,}\right)\cos 2(\mu-\phi)\end{aligned}\right\}(43$$

Moon's Parallax, Sched. IV.

This is of type (35), and gives

$$\left.\begin{aligned}\delta H&=(P'-1)\frac{N_{\circ}\cos 2\nu-L_{\circ}\cos 2\lambda}{e\cos 2\epsilon}\cos 2(\epsilon-\phi)\\ \delta t&=1^{\text{h}}\cdot 977(P'-1)\frac{N_{\circ}\cos 2\nu-L_{\circ}\cos 2\lambda}{He\cos 2\epsilon}\sin 2(\epsilon-\phi)\end{aligned}\right\}\quad . \quad . \quad (44)$$

Sun's Parallax, Sched. IV.

This is of type (37), and gives

$$\left.\begin{aligned}\delta H&=(P_{,}-1)\frac{T-R}{e_{,}}\cos 2(A-\zeta+\phi)\\ \delta t&=-1^{\text{h}}\cdot 977(P_{,}-1)\frac{T-R}{e_{,}H}\sin 2(A-\zeta+\phi)\end{aligned}\right\}\quad . \quad . \quad . \quad (45)$$

Change of Moon's Parallax, Sched. IV.

This is of type (36), and gives

$$\left.\begin{aligned}\delta H&=\frac{-1}{\sigma-\varpi}\;\frac{dP}{dt}\left(4M_{\circ}-\frac{N_{\circ}\sec 2(\mu-\nu)+L_{\circ}\sec 2(\lambda-\mu)}{e}\right)\sin 2(\mu-\phi)\\ \delta t&=\frac{1^{\text{h}}\cdot 977}{(\sigma-\varpi)H}\;\frac{dP}{dt}\left(4M_{\circ}-\frac{N_{\circ}\sec 2(\mu-\nu)+L_{\circ}\sec 2(\lambda-\mu)}{e}\right)\cos 2(\mu-\phi)\end{aligned}\right\}(46)$$

The lunar corrections involving sines are small compared with those involving cosines.

To evaluate these corrections we must compute τ from ϕ reduced to time at $14^{\circ}\cdot 49$ per hour.

In the right ascensional terms, $d\alpha/dt$ and σ are to be expressed in degrees per hour. $d\alpha/dt$ is the hourly change of ☽'s R.A. at time of ☽'s transit, and $d\alpha_{,}/dt$ is the hourly change of ☉'s R.A. at time of ☽'s transit.

Similarly, $d\delta/dt$ is to be expressed in degrees, if σ be in degrees.

δ', P' can be found for the antecedent moments, $57^\circ{\cdot}3 \tan 2(\kappa-\mu)/2\sigma$, and $57^\circ{\cdot}3 \tan 2(\mu-\nu)/(\sigma-\varpi)$, before the time τ.

§ 7. *The Diurnal Tides.*

I shall not consider these tides so completely as the semidiurnal ones, although the method indicated would serve for an accurate discussion, if it be desired to make one.

The important diurnal tides are K_1, O, P.

From Schedule B ii., 1883, we have

$$(\mathrm{O})=\frac{\sin I \cos^2 \frac{1}{2}I}{\sin \omega \cos^2 \frac{1}{2}\omega \cos^4 \frac{1}{2}i} M' \cos \left[t+h-\nu_\circ-2(s-\xi)+\tfrac{1}{2}\pi-\mu'\right].$$

By (9) the coefficient is $\sin 2\Delta/\sin 2\Delta_{\prime\prime}$, and we shall put, as in the case of the semidiurnal tides,

$$M_\circ'=\frac{\sin 2\Delta}{\sin 2\Delta_\prime} M'.$$

Then, since $t+h=\psi+\alpha$,

$$\begin{aligned}(\mathrm{O})&=M_\circ' \cos \left[\psi+(\alpha+\nu_\circ)-2(s-\xi)+\tfrac{1}{2}\pi-\mu'\right]\\ &=M_\circ' \cos \Omega, \text{ for brevity} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (47)\end{aligned}$$

Again, from Schedule C, 1883,

$$(\mathrm{P})=S' \cos \left[t-h+\tfrac{1}{2}\pi-\zeta'\right];$$

Then let $\chi=2(s-h)+\nu_\circ-2\xi-\zeta'+\mu'$, and we have

$$(\mathrm{P})=S' \cos (\Omega+\chi) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (48)$$

Whence

$$(\mathrm{O})+(\mathrm{P})=[M_\circ'+S' \cos \chi] \cos \Omega-S' \sin \chi \sin \Omega.$$

If we put,

$$\begin{aligned}H' \cos (\mu'-\phi')&=M_\circ'+S' \cos \chi\\ H' \sin (\mu'-\phi')&=S' \sin \chi.\end{aligned}$$

$$\begin{aligned}(\mathrm{O})+(\mathrm{P})&=H' \cos (\Omega+\mu'-\phi')\\ &=H' \cos \left[\psi+(\alpha-\nu_\circ)-2(s-\xi)+\tfrac{1}{2}\pi-\phi'\right] \quad . \quad (49)\end{aligned}$$

Where

$$\left.\begin{aligned}H'&=\sqrt{\{M_\circ'^2+S'^2+2M_\circ'S' \cos \chi\}}\\ \text{and} \qquad \tan (\mu'-\phi')&=\frac{S' \sin \chi}{M_\circ'+S' \cos \chi}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (50)$$

The rate of increase of the angle χ is twice the difference of the mean motions of the moon and sun, but it would be more correct to substitute for s and h the true longitudes of the bodies. It follows from (50) that ϕ' has a fortnightly inequality like that of ϕ.

ψ is very nearly equal to T, and where the diurnal tide is not very large we may with sufficient approximation put

$$(\alpha-\nu_\circ)-2(s-\xi)=-(s-\xi).$$

So that with fair approximation

$$(\mathrm{O})+(\mathrm{P})=H' \cos \left[\mathrm{T}-(s-\xi)+\tfrac{1}{2}\pi-\phi'\right] \quad . \quad . \quad . \quad . \quad (51)$$

The synthesis of the two parts of the K_1 tide has been performed in the harmonic method (Report, 1883), and we have

$$(K_1)=f_1 K_1 \cos(t+h-\nu'-\tfrac{1}{2}\pi-\kappa_1).$$

Then, writing $f_1 K_1 = K_o$, we have

$$(K_1)=K_o \cos(T+\alpha-\nu'-\tfrac{1}{2}\pi-\kappa_1) \quad . \quad . \quad . \quad . \quad (52)$$

We have next to consider what corrections to the time and height of high and low water are necessary on account of these diurnal tides.

If we have a function

$$h=B+H\cos 2(T-\phi)+H_1\cos(nT-\beta),$$

where n is nearly equal to unity, and H_1 is small compared with H; its maxima and minima are determined by

$$\sin 2(T-\phi)=-\frac{H_1 n}{2H}\sin(nT-\beta).$$

If $T=T_o$ be the approximate time of maximum, and $T_o+\delta T_o$ the true time, then, since the mean lunar day is 24·84 hours, and the quotient when this is divided by 8π is 0^h·988, we have in mean solar hours,

$$\left.\begin{array}{l}\delta T_o=-0{\cdot}988\dfrac{H_1 n}{H}\sin(nT_o-\beta) \\ \text{And the correction to the maximum is} \\ \delta H=H_1\cos(nT_o-\beta)\end{array}\right\} \quad . \quad . \quad . \quad (53)$$

Again if $T=T_1$ be the approximate time of minimum, and $T_1+\delta T_1$ the true time, then

$$\left.\begin{array}{l}\delta T_1=0{\cdot}988\dfrac{H_1 n}{H}\sin(nT_1-\beta) \\ \text{And the correction to the minimum is} \\ \delta H=H_1\cos(nT_1-\beta)\end{array}\right\} \quad . \quad . \quad . \quad (54)$$

In the case of the correction due to $(O)+(P)$, n is approximately $1-\dfrac{\sigma}{\gamma-\sigma}$, and for the correction due to K_1, n is approximately $1+\dfrac{\sigma}{\gamma-\sigma}$.

§ 8. *Direct Synthesis of the Harmonic Expression for the Tide.*

The scope of the preceding investigation is the establishment of the nature of the connection between the older treatment of tidal observation and the harmonic method. It appears, however, that if the results of harmonic analysis are to be applied to the numerical computation of a tide-table, then a direct synthesis of the harmonic form may be preferable to a transformation to moon's transit, declinations, and parallaxes.

Semidiurnal Tides.

We shall now suppose that M_o is the height of the M_2 tide, augmented or diminished by the factor for the particular year of observation, according to the longitude of the moon's node, and similarly K_o generically for the augmented or diminished height of any of the smaller tides. As

before, let 2μ, 2ζ be the lags of M_2, S_2; and 2κ, generically, the lag of the K tide.

Let $$\theta=t+h-s-\nu_o+\xi.$$

Then θ might be defined as the mean moon's hour-angle, the mean moon coinciding with the true, not at Aries, but at the intersection.

Let the argument of the K tide be written generically $2[\theta+u-\kappa]$.

Then

$$h_2=M_o \cos 2(\theta-\mu)+S \cos 2[\theta+s-h+\nu_o-\xi-\zeta]+K_o \cos 2[\theta+u-\kappa] \quad . \quad . \quad . \quad (55)$$

If we write

$$\zeta_o=\zeta-\nu_o+\xi,$$

and

$$H \cos 2(\mu-\phi)=M_o+S \cos 2[s-h-\zeta_o+\mu]$$
$$H \sin 2(\mu-\phi)=S \sin 2[s-h-\zeta_o+\mu],$$

the first two terms of (55) are united into

$$H \cos 2(\theta-\phi) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (56)$$

with fortnightly inequality of time and height defined by

$$\left.\begin{aligned} \tan 2(\mu-\phi)&=\frac{S \sin 2(s-h-\zeta_o+\mu)}{M_o+S \cos 2(s-h-\zeta_o+\mu)} \\ H&=\surd[M_o^2+S^2+2MS \cos 2(s-h-\zeta_o+\mu)] \end{aligned}\right\} \quad . \quad . \quad . \quad (57)$$

The amount of the fortnightly inequality depends to a small extent on the longitude of the moon's node, since ζ_o and M_o are both functions of that longitude.

For the K tide we have

$$K_o \cos 2(\theta+u-\kappa)=K_o \cos 2(u-\kappa+\phi) \cos 2(\theta-\phi)$$
$$-K_o \sin 2(u-\kappa+\phi) \sin 2(\theta-\phi).$$

Hence

$$\left.\begin{aligned} \delta H&=\quad K_o \cos 2(u-\kappa+\phi) \\ \delta\phi&=-\frac{K_o}{2H} \sin 2(u-\kappa+\phi) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (58)$$

It is easy to find from the Nautical Almanac (see Moon's Libration) the exact time of mean moon's transit on any day, and then the successive additions of $12^h\cdot420601$ or $12^h\ 25^m\ 14^s\cdot16$ give the successive upper and lower transits. The successive values of $2(s-h)$ may be easily found by successively adding $12^\circ\cdot618036$ to the initial value at the time of the first transit of the mean moon, and ϕ may be obtained from the table of the fortnightly inequality for each value of $2(s-h)$.

The function u is slowly varying, e.g., for the K_2 tide $2u=2(s-\xi)+2(\nu_o-\nu'')$, and the increment of argument for each $12^h\cdot420601$ may be easily computed once for all, and added to the initial value.

In the case of the diurnal tides it will probably be most convenient to apply corrections for each independently, following the same lines as those sketched out in § 5.

The corrections for the over tides M_4, S_4, &c., and for the terdiurnal

and quaterdiurnal compound tides, would also require special treatment, which may easily be devised.

At ports, where the diurnal tide is nearly as large or larger than the semidiurnal, special methods will be necessary.

Although the treatment in terms of mean longitudes makes the corrections larger than in the other method, yet it appears that the computation of a tide-table may thus be made easier, with less reference to ephemerides, and with amply sufficient accuracy.

Report of the Committee, consisting of Mr. ROBERT H. SCOTT (*Secretary*), Mr. J. NORMAN LOCKYER, Professor G. G. STOKES, Professor BALFOUR STEWART, *and* Mr. G. J. SYMONS, *appointed for the purpose of co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year* 1861. *Drawn up by* Mr. R. H. SCOTT.

THE Committee have the honour to forward, for the inspection of the members of the Association, a copy of the Charts for the month of March 1861, with some specimens for January of the same year, and the complete number for February which appeared some years ago. These documents have recently arrived from the Mauritius.

As the work has now made decided progress, the Committee have applied for and obtained the grant of 50*l.* placed at their disposal by the General Committee.

As soon as the requisite documents are received from Dr. Meldrum, the Committee will submit a formal account of their expenditure with the necessary vouchers.

Report of the Committee, consisting of Mr. JAMES N. SHOOLBRED (*Secretary*) *and* Sir WILLIAM THOMSON, *appointed for the reduction and tabulation of Tidal Observations in the English Channel, made with the Dover Tide-gauge; and for connecting them with Observations made on the French coast.*

YOUR Committee herewith beg to submit the High Water and the Low Water Observations for the years 1880, 1881, 1882, and 1883, obtained from the records of the self-registering tide-gauges at the ports of Dover and of Ostend respectively.

The observations, in order to facilitate comparisons, are reduced to Greenwich time and to the common datum-plane of 20 feet below the Ordnance datum of Great Britain.

As the reduction and tabulation of the present series of tidal observations has proved a longer operation than was anticipated, there has been hardly sufficient time to consider the best form in which those observations should be placed for comparison, nor for the more suitable deductions which may be drawn from such comparison.

Your Committee, therefore, request to be reappointed.

Report of the Committee, consisting of Professor G. FORBES (*Secretary*), Captain ABNEY, Dr. J. HOPKINSON, Professor W. G. ADAMS, Professor G. C. FOSTER, Lord RAYLEIGH, Mr. PREECE, Professor SCHUSTER, Professor DEWAR, Mr. A. VERNON HARCOURT, *and* Professor AYRTON, *appointed for the purpose of reporting on Standards of White Light. Drawn up by* Professor G. FORBES.

THE experimental work of the Committee during the past year has not been extensive, as they had no funds at their disposal for experimental research, and they have been chiefly occupied with reviewing what has been done in the past and laying plans for future operations.

Lord Rayleigh has constructed an instrument which he calls a monochromatic telescope, by means of which the illuminated screens of a photometer may be examined, allowing light only of one definite colour to pass. It was hoped by Lord Rayleigh that experiment might show that, with some suitably chosen colour, this instrument, used with any ordinary photometer, would, in comparing lights of different intensities and temperatures, give to each a candle-power which would be sufficiently accurate to represent for commercial purposes the intensity of the light. The Secretary has made some experiments at the Society of Arts, where he was kindly permitted to use the secondary batteries and glow lamps; but the results so far are not definite enough to justify their publication.

Mr. Vernon Harcourt has been engaged on an investigation on the barometrical correction to his pentane standard, and on another concerning the possibility of using lamp-shades as a protection from air currents. His researches are communicated independently to the meeting.

Captain Abney and General Festing have continued their observations on the intensity of radiations of different wave-lengths from incandescent carbon and platinum filaments at different temperatures, which will go far to assist the Committee in their work.

Other isolated experiments have been made by members of the Committee, which will be published in due course.

Most of the members have examined the experiments of the Trinity Board at the South Foreland.

Existing Standards.

A consideration of existing standards convinces the Committee that the standard candle, as defined by Act of Parliament, is not in any sense of the word a standard. The French 'bec Carcel' is also liable to variations; and with regard to the molten platinum standard of Violle, it seems that the difficulty of applying it is so great as to render its general adoption almost impossible.

With regard to the so-called standard candle, the spermaceti employed is not a definite chemical substance, and is mixed with other materials, and the constitution of the wick is not sufficiently well defined. Hence it is notorious that interested parties may prepare candles conforming to the definitions of the Act which shall favour either the producer or consumer to a serious extent. In view of these defects of the standard candle, it is a matter of great importance that a standard of light should be chosen which is more certain in its indications.

The Committee have looked into the merits of different proposed standards, and the majority feel satisfied that, for all the present com-

mercial requirements, the pentane standard of Mr. Vernon Harcourt—since it has no wick and consumes a material of definite chemical composition—when properly defined, is an accurate and convenient standard, and gives more accurately than the so-called standard candle an illumination equal to that which was intended when the Act was framed.

Yet the Committee, while desiring to impress the Board of Trade and the public with these views, do not feel inclined at present to recommend the adoption of any standard for universal adoption until, further information on radiation having been obtained from experiment, they may learn whether or not it may be possible to propose an absolute standard, founded, like electrical and other standards, on fundamental units of measurement—a standard which, for these reasons, would be acceptable to all civilised nations. They are, however, inclined to look upon the pentane lamp as an accurate means of obtaining an illumination to replace the so-called standard candle.

Proposed Experimental Researches.

Radiation is measured as a rate of doing work, and consequently radiation might be measured in watts. The illumination (or luminous effect of radiation) depends partly upon the eye, and is a certain function of the total radiation. This function depends upon the wave-length of the radiation, or on the different wave-lengths of which the radiation, if it be compound, is composed. This function of the radiation perceived by the eye is partly subjective, and varies with radiations of different wave-lengths and with different eyes. Thus the illumination cannot, like the radiation, be expressed directly in absolute measurement. But the connection between the illumination and the radiation can be determined from a large number of experiments with a large number of eyes, so as to get the value of the function for the normal human eye. This function, however, is constant only for one source of light, or, it may be, for sources of light of the same temperature. It appears, then, that, in the first instance at least, a standard should be defined as being made of a definite material at a special temperature.

The energy required to produce a certain radiation in the case of a thin filament of carbon or platinum-iridium heated by the passage of an electric current can be easily measured by the ordinary electric methods, and the radiation may be measured by a thermopile or a bolometer, which itself can be standardised by measuring the radiation from a definite surface at 100° C., compared with the same at 0° C. The electric method measures the absorption of energy; the thermopile measures the total radiation. These two are identical if no energy is wasted in convection within the glass bulb of the lamp, by reflection and absorption of the glass, and by conduction from the terminals of the filament. Captain Abney and General Festing have come to the conclusion that there is no sensible loss from these causes. The Committee propose to investigate this further. This constitutes a first research.

No research is necessary to prove that with a constant temperature of a given filament the luminosity is proportional to the radiation, because each of these depends only upon the amount of surface of the radiating filament. It will be necessary, however, to examine whether with different filaments it be possible to maintain them at such temperatures as shall make the illumination of each proportional to the radiation. This will be the case if spectrum curves, giving the intensity of radiation in

terms of the wave-length when made out for the different sources of light, are of the same form. Thus a second research must be undertaken to discover whether the infinite number of spectrum radiation curves, which can be obtained from a carbon filament by varying the current, are identical in form when the filament is changed, but the material remains so far as possible of constant composition.

It will be an object for a later research to determine whether, when the radiation spectrum curve of any source of light has been mapped, a similar curve can be found among the infinite number of curves which can be obtained from a single filament.

The next step proposed is to examine a large number of carbon or of platinum-iridium filaments, and to find whether the radiation spectrum curve of different specimens of the same material is identical when the resistance is changed in all to x times the resistance at 0° C. If this law be true, a measurement of the resistance of the filament would be a convenient statement of the nature of the radiation curve. If, then, a number of filaments were thus tested to give the same radiation spectrum curve, their luminosities would in all cases be proportional to their radiations, or (if there be no loss in convection, conduction, absorption, and reflection) proportional to the electrical energies consumed.

Thus it might be hoped to establish a standard of white light, and to define it somewhat in the following manner:—*A unit of light is obtained from a straight carbon filament, in the direction at right angles to the middle of the filament, when the resistance of the filament is one-half of its resistance at 0° C., and when it consumes 10^9 C.G.S. units of electrical energy per second.*

Since Mr. Swan has taught us how to make carbon filaments of constant section by passing the material of which they are composed through a die, it is conceivable that another absolute standard should be possible—viz., a carbon filament of circular section, with a surface, say, $\frac{1}{100}$ sq. centimètre, and consuming, say, 10^9 C.G.S. units of energy per second.

Whether such standards are possible or not depends upon the experiments of the Committee. The probability of success is sufficient to render these experiments desirable.

Proposed Later Experimental Researches.

Should these hopes be realised, and an absolute standard of white light thus obtained of a character which would commend it to the civilised world, it would then become an object of the Committee to find the ratio of luminosity when the radiation spectrum curve of the standard filament is varied by varying the current, and consequently the resistance of the filament.

Thus, by a large number of subjective experiments on human eyes, a multiplier would be found to express the illumination from the standard lamp, with each degree of resistance of the filament.

A research, previously hinted at, would then be undertaken—viz., to find whether the radiation spectrum curves of all sources of illumination agree with one or other of the curves of the standard filament. It is not improbable that this should be the case except for the high temperature of the electric arc.

Should this be found to be true, then photometry would be very accurate, and the process would be as follows:—*Adjust the standard filament until its radiation spectrum curve is similar to that of the light to be*

compared. (This would probably be best done by observing the wave-length of the maximum radiation, or by observing equal altitudes on either side of the maximum, the instruments used being a spectroscope and a line thermopile or a bolometer.) The total radiation of each is then measured at equal distances by the thermopile. The resistance of the filament is measured, and its intensity in terms of the unit of white light obtained therefrom by the previous research. The luminosity of the compared source of light is then obtained directly.

The Committee desire to be reappointed, and to enable them to carry out the researches indicated they ask for a grant of 30*l.*

Second Report of the Committee, consisting of Professor BALFOUR STEWART (*Secretary*), Mr. J. KNOX LAUGHTON, Mr. G. J. SYMONS, Mr. R. H. SCOTT, *and* Mr. JOHNSTONE STONEY, *appointed for the purpose of co-operating with* Mr. E. J. LOWE *in his project of establishing a Meteorological Observatory near Chepstow on a permanent and scientific basis.*

SINCE their reappointment in 1884 this Committee have met twice, and have placed themselves in correspondence with Mr. Lowe.

In this correspondence the Committee have expressed their opinion that the establishment of a permanently endowed meteorological observatory on a good site, such as that of Shire Newton, is a matter of undeniable scientific importance.

The attitude which the Committee have taken will be rendered apparent by the following letter written by their Secretary to Mr. Lowe:—

'The Committee request me to point out to you that the main feature of your proposal, which interests the British Association and the scientific public generally, is the prospect which it holds out of the establishment of a *permanent* institution by means of which meteorological constants could be determined, and any secular change which may take place therein in the course of a long period of years be ascertained. It will be for you and the local authorities to decide what amount of work of *local interest* should be contemplated, and on this will the scale of the observatory mainly depend. The Committee are therefore unable to say what amount of capital would be required. They would point out four conditions which they hold to be indispensable:—

'1. The area of ground appropriated should be sufficient to ensure freedom from the effect of subsequent building in the neighbourhood.

'2. A sufficient endowment fund of at least 150*l.* annually should be created.

'3. The control should be in the hands of a body which is in itself permanent as far as can be foreseen.

'4. The land for the site shall be handed over absolutely to the above-mentioned governing body.'

This communication from the Committee is now under the consideration of Mr. Lowe and his friends, but until the precise amount of the local meteorological requirements is ascertained and further progress is made in the scheme the Committee consider that they would not be justified in any more prominent action than that which they have already taken.

They would request their reappointment, and that the unexpended sum of 25*l.* be again placed at their disposal.

Report of the Committee, consisting of Professor BALFOUR STEWART (*Secretary*), Sir W. THOMSON, Sir J. H. LEFROY, Sir FREDERICK EVANS, Professor G. H. DARWIN, Professor G. CHRYSTAL, Professor S. J. PERRY, Mr. C. H. CARPMAEL, *and* Professor SCHUSTER, *appointed for the purpose of considering the best means of Comparing and Reducing Magnetic Observations. Drawn up by* Professor BALFOUR STEWART.

IN presenting their report to the British Association the Committee would begin by referring to the appendix, in which are embodied suggestions of great value which they have received from men of science at home and abroad. The Committee desire to express their thanks to the authors of these contributions.

While a final discussion of these communications cannot be attempted in this first report, it is nevertheless evident that magneticians are not agreed as to the best method of determining absolutely the solar-diurnal variations of the three magnetic elements—that is to say, the diurnal variation resulting after the elimination of all disturbed observations. The point in dispute is the method of distinguishing and separating the disturbed from the undisturbed observations. On the whole, the feeling is against the method of Sabine, on account of the arbitrary nature of his separating value.

An alternative method has been proposed by Dr. Wild, Director of the Central Russian Observatory (Appendix, No. VII.). This method seems to be in some degree analogous to that pursued at Greenwich (Appendix, No. IX.). Dr. Wild selects those curves which appear to the eye to be free from the short-period irregularities characteristic of disturbances, and considers the results obtained from their measurement to embody a trustworthy representation of the solar-diurnal variation for the time and place in question. He finds a remarkable uniformity and simplicity of type in the variation as given by the different selected curves.

While the Committee recognise in this a method which may ultimately meet with general acceptance, they think there are various points connected with it which require investigation.

In the first place, it would be desirable to prove, by means of an exhaustive discussion of some one element—as, for instance, the declination—to what extent curves selected by the eye do, as a matter of fact, present this uniformity and simplicity of type.

There are abundant materials available for this purpose at the Kew Observatory, and it is hoped that through the kindness of the Kew Committee this point may eventually be settled.

Again, it would be desirable to ascertain whether the apparently normal days at one station coincide with those at another; and, if so, whether there is a definite or nearly definite relation in type and range between the corresponding smooth curves of two widely separated stations of not very dissimilar latitude.

This point will form one of the subjects of a discussion undertaken by Sir J. Henry Lefroy, who proposes to compare the curves of Toronto and those of Greenwich together for the years 1849–53.

The Committee are of opinion that these are steps which might at once be taken, so as to push on this part of the subject.

The Committee would call attention to the completeness of the magnetical information which is given by the present method of publication adopted by the Astronomer Royal. He now gives, in addition to the mean values of the magnetic elements for each day and the mean diurnal curves for each month, the amplitude of the diurnal curve for each day, and particulars of all disturbances, small as well as large. (See Appendix, No. IX.)

Until a method is generally accepted for determining the normal solar-diurnal variation, it seems premature to raise any discussion on the best way of estimating disturbances, since these cannot well be measured except from the basis of such a normal.

The Committee would, however, allude to various investigations, chiefly connected with disturbance, which are being undertaken by some of its members. The thought seems generally to have occurred that disturbances may denote the method by which the earth *rights itself* with respect to the magnetic forces acting upon it (see Appendix, No. II., paragraphs 11 and 12), and this idea underlies the various researches about to be named.[1]

The first of these is that already mentioned as having been taken up by Sir J. H. Lefroy, with the concurrence of the Astronomer Royal—namely, a comparison of magnetic movements photographically recorded at Toronto and Greenwich in the years 1849–53. Stations so far asunder (3,100 miles), and on different continents, appear calculated to throw light on many questions which are not much advanced by comparison of stations in geographical proximity.

The following are *primâ facie* conclusions which may require modification when the work has been gone through, but which already seem to have a bearing on the physical explanation of the phenomena :—

a. A similar state of magnetic weather, so to speak, prevails generally at both stations, so that where numerous or extensive deviations from normal regularity occur at the one, there is generally something corresponding at the other.

b. The correspondence very seldom amounts to similarity of movement or identity of time.

c. The changes of declination at Toronto are more rapid than at Greenwich. This is especially observable about the time of the morning easterly extreme. Bold sweeping curves with a long time measure are much less common at Toronto than at Greenwich, and can seldom be identified.

d. On the other hand, shocks of small angular amount breaking a uniform line are often capable of identification, and are simultaneous, or nearly so, at both stations.

e. Although the declination was westerly at both stations, the movements of disturbance are very frequently, probably usually, in opposite directions at any given time—easterly at Greenwich, or decreasing the absolute declination, when they are westerly, or increasing it, at Toronto.

f. The same days would generally be selected to form normal curves at both stations.

[1] A similar idea seems to have occurred to Dr. Wild (see foot-note to his communication, Appendix, No. VII.).

g. Slight auroral displays in Canada generally produce a marked effect at Toronto, but none at Greenwich.

h. It is not easy to answer the question whether a state of disturbance succeeding one of calm begins or ends at the same time at both stations, neither beginning or ending being, in general, sufficiently definitely marked.

i. It appears impossible to assign a value based on angular movement alone which will be a valid test, whether such movement is due to disturbing causes or not.

j. Angular movements at Toronto appear to be larger than at Greenwich, the magnets being (in 1849–50) similar—namely, 2 feet in length.

The second research is by the Rev. S. J. Perry and Professor Stewart, who, with the sanction of the Kew Committee, are engaged in a comparison of the simultaneous disturbances of the declination at Stonyhurst and at Kew. Calling the first S, and the second K, they have obtained the following preliminary results, which may, however, ultimately require some modification :—

(1) S is always greater than K, or the ratio $\frac{S}{K}$ is always greater than unity.

(2) This ratio appears to depend in some way on the duration of the disturbance.

(3) But not, as far as can be seen at present, upon its magnitude.

A third research is by Professor Stewart and Mr. W. Lant Carpenter, who are making a preliminary trial of four years of Kew declination disturbances (separated by Sabine's method), in order to ascertain whether the aggregate daily disturbance depends upon the relative position of the sun and moon, and also whether it is affected by meteorological storms. The following provisional result has been obtained from the years 1870–73 in which the lunation is divided into 8 parts, (0) denoting new, and (4) full moon.

Mean Daily Aggregate of Disturbance of Declination at Kew.[1]

(Unit $\frac{1}{100}$th of an inch, measured on the curve.)

(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
111	114	104	95	83	94	107	101

The Committee desire to draw the attention of magneticians to the urgent need of obtaining more accurate knowledge than we possess at present of the daily variation of the vertical force. No attempt to fix the cause of the daily variation can be made until the daily variation of each component of the magnetic force is known.

In conclusion, the Committee desire their reappointment, with the addition to their number of Captain Creak and of Mr. G. M. Whipple, Director of the Kew Observatory, and they would request that the sum of 50*l.* should be placed at their disposal, to be spent as they may think best on the researches mentioned in this report.

[1] The late Professor J. Clerk Maxwell was, it is believed, the first to suggest that the lunar-diurnal variation of the earth's magnetism may be caused by distortion, and Dr. Schuster has suggested that, if there is found to be a relation between magnetic disturbances and atmospheric storms, it may be of the same nature.

APPENDIX.

Suggestions for the Committee on Magnetical Reductions.

I. By Professor Balfour Stewart, F.R.S.

1. The following suggestions are founded on the methods proposed by several magneticians, including Sabine, Broun, Lefroy, Capello, and Buys Ballot. To Senhor Capello I am especially indebted for the trouble he has taken in explaining his views, with which these suggestions are almost identical.

2. The measurements derived from self-recording magnetographs may be used for two purposes, the first being to ascertain the *solar diurnal variation*, by which name we designate that variation which is exhibited by comparatively undisturbed observations. The second of these purposes is to ascertain *the laws which regulate disturbances.* Now disturbances may act in two ways. *First*, they may exhibit a diurnal variation different from that of the undisturbed observations, which we may call the *disturbance diurnal variation*; and, *secondly*, they may exalt or depress the day's value of the particular element in question.

As a matter of fact I believe they act in both these ways. It appears to me that it is of very great importance that these two effects of disturbance should be exhibited and studied together, and yet not improperly mixed up with one another.

3. Let me explain my meaning with reference to the method of Sabine, which I believe to be, in many respects, an excellent one. Sabine did a very great deal in finding out and exhibiting the diurnal variations of the disturbed and undisturbed observations, but he did not greatly study, along with these, the effect of disturbances in altering the daily mean values of an element, so that it was reserved for Broun to discover that there were changes in the daily values of the horizontal force which were practically simultaneous at the various stations of the globe. Let us first of all consider the hourly values of declination, as this element presents fewest difficulties.

Declination.

4. Here, I imagine, the first thing is to determine the *solar diurnal variation*, or that presented by the comparatively undisturbed observations, and for this purpose I fail to see a better plan than that proposed by Sabine. This method may be described as follows:

5. Suppose that we have hourly observations at a station, then, first of all, we should arrange these into monthly groups, each hour by itself. We should then reject, as disturbed observations, all those which differ by more than a certain amount from their respective normals of the same month and hour, the normals being the hourly means in each month after the exclusion of all the disturbed observations. For the purpose of ascertaining the true solar diurnal variation, it seems probable that a considerable choice might be allowed in selecting the separating value implied in the above process, one value serving, *for this purpose*, probably as well as another a little above or below it.

6. Perhaps under ordinary circumstances a value which will exclude as disturbed about one-twentieth of the whole body of observations will be found convenient.

7. Let us now imagine that we have determined by this process

the undisturbed normals for each hour, for each month. I agree with Sir J. H. Lefroy in thinking that the best plan of investigating disturbances is, in the first place, to obtain the various departures of individual observations from their respective normals for that month and hour. It would be desirable to embody these departures in a fresh table, in which (except for those who are colour-blind) the negative departures might be given in red ink and the positive in black.

8. In this table, at the right of the twenty-four departures for the various hours of the day, I should represent the mean departure for that whole day either in red or black. It would thus be seen, at a glance, whether the average of the whole day was affected by disturbance, in what direction, and to what extent.

9. It is here assumed that, during the month in question, no alteration of scale value or other instrumental change has taken place. Nevertheless at stations which have a considerable secular variation of declination, and for which this is known, it might be desirable to introduce, say to the extreme right, a column embracing a small residual correction, applicable to each day's departures, on account of secular change.

10. I imagine that a monthly table, constructed after the method which I have described, will afford a full and satisfactory basis for the discussion of disturbances.

11. It is probable that the smaller departures will follow the law of the ordinary solar diurnal variation, and, in that case, there should be as many *black* as *red* sums in these minor departures, or, in other words, the algebraic sum of these should be zero, while the sum taken without respect to sign or colour should represent the amount of oscillation or disturbance obeying the ordinary law, this being a point which it is of interest to determine. No doubt the larger disturbances will obey some other law, and it will be necessary to separate them into two categories, those *increasing* and those *diminishing* the declination. Here I should follow Dr. Buys Ballot's advice, and allow the observations themselves to determine where the one law ends and the other begins. It is just possible that sometimes the day's mean may be decidedly different from what it ought to be, and yet the diurnal variation for that day be as nearly as possible the same as for undisturbed observations. A table, such as that now described, will show, at a glance, whether such a state of things ever takes place.

Horizontal and Vertical Force.

12. The horizontal and vertical force magnetographs are different from the declination magnetograph, inasmuch as their indications are affected by change of temperature, by loss of magnetism, and possibly, in the case of the vertical force instrument, by other circumstances not well understood.

13. It will be noticed that, in treating the declination results by Sabine's method, we perform our operation upon the individual declination values. Now it might be said, why not (your object being to find the solar diurnal variation) take the departure of the individual hours of a day from the mean of that day, and treat each month's departures by Sabine's method?

14. The reply would be that the mean of a day is more likely to be affected by disturbance than the monthly mean of an hour. For disturbances, when they come, generally affect several consecutive hours, thus

altering the daily mean, but, on the other hand, they are less likely to affect the same hour during consecutive days. Were we able to obtain daily means of declination, unaffected by disturbance, it would be better to adopt this method of treatment, because it would obviate the introduction of any residual correction due to the progress of secular change or annual or semi-annual variation. Now in the force magnetographs the case is different. Here there is a certainty that some—perhaps even a considerable—change will be produced in the values belonging to a given hour in the course of a month from instrumental changes alone, so that treating the observations after the manner pursued with the declination might lead to erroneous results.

15. On the other hand, if there were no disturbance, the difference of the various hourly observations of a day, from the mean of that day, would give us a good indication of the solar diurnal variation, provided the diurnal range of temperature was inconsiderable, as is generally the case for self-recording instruments.

16. These remarks render it manifest that some method of obtaining probable values of the undisturbed daily means is, in the case of the force instruments, of vital importance, and Senhor Capello has adopted a method of this kind in his treatment of his force observations. I would venture to remark that the most unexceptionable basis upon which to determine the undisturbed daily means of horizontal and vertical force would seem to be given by the information already assumed to be obtained from the declination magnetograph for the same month.

17. Here, as a result of the application of Sabine's method, we have rejected a certain number of hourly observations as disturbed. Now let us reject, as a preliminary step to something more complete, precisely the same hourly observations of the horizontal and vertical force as being, in all probability, disturbed, and make use of the remainder, or of that part of the remainder which represents whole, or nearly whole, days free from disturbance, to aid us in determining, by a curve, the most probable values of the undisturbed daily means. I here assume that there is no sudden jump in the month's readings from change made on the instrument or any other cause; if there be such, the portions before and after the jump will have different values, and must be treated by appropriate methods which need not here be discussed. Suffice it to say that, by rejecting from the month's observations those hours which were separated as disturbed in the declination, and treating the remainder in the manner suggested, we obtain, aided, perhaps, by a slight equalisation, numbers representing very nearly the undisturbed daily values of the records given by the instruments.

18. Having obtained these, our next operation is to obtain the hourly differences from each day's undisturbed mean. These differences, so obtained, we propose to treat in the same manner in which we treated actual declination observations. It is, therefore, to *these differences* that Sabine's process should be applied, so that ultimately, when we have applied it, we shall obtain those departures of each hour from the daily mean which characterise undisturbed observations—in other words, we obtain the solar diurnal variation.

19. Having obtained this, we have at once the means of obtaining a table similar, in all respects, to that which we have recommended for the declination. For instance, if the departure of a given hour of a given day from the undisturbed mean of that day were +9 whereas, according

to the solar diurnal variation for undisturbed observations, it should have been +3, the number +6 would be inserted in the table, and so on.

20. It will be seen at once that we shall be able to ascertain by the method now described, if disturbance (as Broun supposed) alters the daily average values of the horizontal force. For in the horizontal force instrument any comparatively short period change of average daily value is hardly likely to be caused by instrumental alteration, but is most probably due to magnetic causes, more especially if the same change takes place simultaneously at various stations.

There are, however, more serious difficulties connected with the vertical force instrument, but into these I cannot now enter.

II. By Sir J. Henry Lefroy, K.C.M.G., F.R.S.

1. The statement of the question appears to assume that the first, or chief, object of continuous automatic registers of magnetic changes is to extend the large number we already possess of mean determinations of solar-diurnal variations, and to add fresh numerical or quantitative values of the deviations from these means, produced by the causes we class as irregular.

2. This appears to me to be persevering in a path we have been travelling for forty years without reaching, or even seeing the way, to any physical explanation of the phenomena.

3. There are about seventy-five points on the globe at which the diurnal variation, including disturbances, has been determined by eye-observations, hourly or bi-hourly, with more or less completeness and precision. The irregular, or non-solar-diurnal, effects have as yet been eliminated for a few only (ten or twelve) of these points, but this number has proved sufficient to bring out pretty clearly certain general laws to which no key has yet been found.

4. Unless it can be shown that a multiplication of numerical data promises to bring us to a conclusion, I am inclined to think that the laborious compilation of more data of the same kind by measurements from photographic registers, which are less precise than the old eye-observations, is rather a misdirection of energy, unless indeed at stations widely remote from any others, and where new facts may be expected (see, for example, the very anomalous diurnal curve at Reikiavik, Iceland, 'Athabasca volume,' p. 297). The recent circumpolar stations would have come into this category if they had used self-recording instruments.

5. Airy and Sabine have both taken $\pm 3'{\cdot}3$ of declination as the measure of a disturbed observation at Greenwich and Kew respectively.[1] If it is true, as remarked by Professor Balfour Stewart (par. 5), that the precise measure is of no great consequence, is it worth while to spend much time over making out a new value independently for any part of Great Britain?

6. The arbitrary nature of Sabine's mode of treatment of observations is to me a strong objection to the continuance of it.

For example, he threw out as disturbed all the observations at Point Barrow which deviated $22'{\cdot}87$ from the normal,[2] and at Fort Carlton[3] all which deviated $6'{\cdot}0$. But I think I have sufficiently shown that in high latitudes in America the mean value of disturbance is about three times

[1] *Phil. Trans.* 1860–1863. [2] *Phil. Trans.* 1857. [3] *St. Helena*, vol. ii.

as great in the early morning hours as it is in the afternoon. Consequently we must either disregard a great many observations by day, which are really disturbed, or include a great many by night, which are not, unless we say that instability is the same thing as disturbance.

7. What, then, is to be done with the photographic registers? How can they be compared unless by ordinates, measured at points agreed upon, such as the Göttingen hours?

I reply (1) that I think that each observer should minutely scan his own records, and note the time, direction, and amount of movements. (2) That the efforts of magneticians should be addressed to the cheap publication and prompt interchange of the registers of each week, reproduced and reduced by photography to a uniform scale, say 15mm. to 1 hour, with a view to the discovery of periodically recurring movements of whatever nature; of movements apparently local, or not generally traceable; and of movements which were general, in one or more elements, over a large part of the earth's surface.

It hardly meets this suggestion to say that we have hundreds of projections of disturbances already, and that nothing has come of it. It is true; but these projections are scattered through many volumes, are upon all sorts of scales, and are rarely comparative.

8. The student having by his eye-comparison grasped the general features of the movements constituting disturbance at some particular epoch, or presenting an exceptional character, the need of measurements would arise, and if a reference to the mean of the day or the mean of n days or of the calendar month is necessary, such mean can be ascertained. I am not sure that it often will be, and I doubt whether our adherence to the calendar month is rational. Why should movements on May 31 be referred to the mean for May rather than the mean for June? The more accurate, though more laborious, plan would be to refer them to the mean for May 31 $\pm$ 10 days.

9. The end of the needle which points to the equatorial region has in every locality a mean position in relation to the meridian from which it is continually deviating, and to which it always returns. It appears to me open to question whether the relation of the direction of the movement to the absolute declination, as increasing it or diminishing it, has much to do with the question. At least it seems to assume that the normal position is due to the same physical causes as produce the deviations, and therefore I think that the deviations, whether of the polar or equatorial end, should be simply noted as east or west without regard to sign. In the southern hemisphere it is the equatorial end that we observe. Regions where the north end is actually directed to the south, as at Port Kennedy and the *Alert's* winter quarters (1875–6), will require negative signs.

10. It seems probable (1) that the mean position of the needle above referred to is always perpendicular to the direction of electric currents in the crust of the earth, or the atmosphere, or both, originating in a thermo-electric action of the sun on the meridian, and propagated north and south from the ecliptic; (2) that the position of the meridian of the place, in reference to the sun, determines the direction of the mean deviation of the needle from its normal position or the mean solar-diurnal movement, and that the amount is determined by a balance of forces still to be clearly defined. The amount is known at a sufficient number of stations to test any law laid down.

11. It appears that so long as the sun is above the horizon of the place, there is comparatively little disturbance. In other words, the hours most habitually disturbed are before sunrise and after sunset. It is true that disturbances, once originated, display themselves simultaneously at distant localities, irrespective of the hours of the day; but the above seems to give probability to a conjecture that they originate in that hemisphere from which the sun is absent, and on those meridians which are at the time in the condition of greatest mean disturbance.

12. Of known physical causes, the influence of sudden internal perturbations analogous to those which become perceptible to our senses, as earthquakes and the like, seems to me the most nearly to meet the observed facts. They cannot be due to any atmospheric cause. Nor is it very probable that anything extra-terrestrial, such as solar perturbations, can operate with such vigour and suddenness upon our electric circulation. That there is a sympathy or correspondence between seismic disturbance and magnetic disturbance has been often shown, but I am not aware that it has ever been followed up in a comprehensive way.

That this view implies some relation between the internal perturbations referred to, and the position of the part of the globe in which they originate in respect to the sun, as being in the hemisphere turned away from him, appears to follow, but I do not see any absurdity in such a supposition.

13. Since continuous automatic registration affords a means of tracing the correspondence of either short-time or long-time movements with other observed phenomena, seismic movements, solar outbursts, auroral discharges, and atmospheric changes, for example such as no multiplication of eye-observations can do, this appears to me the first use to put it to. Forty years of eye-observation have added enormously to our store of facts, but brought us little if anything nearer a theory. Is it not time to try some other line of investigation?

14. With respect to the behaviour of the horizontal component during disturbances, depending as it does upon two variables, the dip and total force, it is rather unsatisfactory, but we have good and extensive data, and whatever principle of measurement or solution is applied to, the declination, must, I apprehend, be extended to this element.

15. With respect to the vertical component I doubt whether the available data are as yet comparable in precision with those of the other two elements. I saw, however, some admirable curves at Toronto, produced by Professor Carpmael's new instrument (I feel doubtful now whether they were curves of Δ Y or $\Delta\theta$), which had all the character and freedom of those of the horizontal force, and when these have been worked up and discussed we shall know a good deal more about the influence of disturbances in increasing or diminishing the dip and total force.

III. By Professor Schuster, F.R.S.

I should like to submit to the Committee a few points to which their attention, in my opinion, might with advantage be directed.

It is now nearly fifty years since Gauss applied the method of expansion in spherical harmonics to the elements of terrestrial magnetism. He considered his results only as preliminary, on account of the incompleteness of the data on which he had to work.

We possess now so much more information on the mean value of the terrestrial elements at different places, that, it seems to me, a repetition of the calculations of Gauss would lead to valuable results. Such a calculation would not only be of theoretical importance. For we might in this way detect many points of interest, as, for instance, where if anywhere masses of iron are present near the surface of the earth in sufficient quantity to affect the magnetic elements. At such places we should expect the harmonic analysis to give correct results only if extended to a large number of terms, so that if we confine ourselves, like Gauss, to four or five terms only, and find considerable differences between the calculated and observed values at some part of the earth's surface, we should have our attention specially directed to that part.

It is only by a reduction such as that of Gauss that we shall be able to find out where we require further observations, and where a multiplication of observations is unnecessary.

It would be very desirable if we could extend the analysis of spherical harmonics to the daily variation of the elements and to magnetic disturbances generally. But it seems to me that if, as is likely, these changes are due to electric currents either above or below the earth's surface but near it, the analysis would have to be carried to a large number of terms before it would yield satisfactory results. But this, of course, is a matter which the actual calculation only can settle, and we ought therefore, at any rate, to make the attempt to apply the method of Gauss to the daily variation. With our present knowledge of that variation at different places of the earth's surfaces, there ought to be no difficulty in finding out whether five or six terms are sufficient to represent it, taking account, of course, also of those terms which have their origin outside the earth.

Some observations of Sabine made near the magnetic pole[1] seem to point to the fact that part of the diurnal variation is due to a vertical component of an electric current crossing the earth's surface. Whether such a vertical component exists can be determined without difficulty, for we can actually measure it by taking the line integral of magnetic force at a given time over a closed curve on the earth's surface.

I should like, therefore, to propose to the Committee to find out, in the first place, what determinations of the magnetic elements ought to be taken account of in the reductions. In countries where we possess a great number of accurate data, it would seem only an increase of labour to take account of all of them. On the other hand, where we possess few measurements we should in all probability have to use even approximate determinations. It is a point for the Committee to decide whether we ought to take the places which are to be included in the calculation spread as evenly as possible over the earth's surface, or whether a preponderance should be given to places near the magnetic poles or at other places of special importance. Also whether the more accurate observations ought to be weighed. Should the Committee approve of these reductions, it would be well to ask at the next meeting of the Association for a sufficient grant to engage the assistance of one or two computers.

I should like in conclusion to submit a few observations respecting the remarks made by Professor Balfour Stewart and Sir Henry Lefroy. The function of the Committee seems to me to be a double one. In the

[1] See *Encyclopædia Britannica*—Terrestrial Magnetism (art. Meteorology).

first place, they are to discuss the best methods of reducing magnetic observations; but, before these methods can be put into execution, we must secure that the observations taken at different places are sufficiently homogeneous to admit of a common treatment. As we have to deal not with the individual observations, but with numbers which have already been reduced at the different observatories, it is clearly of importance that these preliminary reductions should be done everywhere in the same manner. Professor Stewart's suggestions refer exclusively to this point, while Sir Henry Lefroy rather discusses the question as to how the measurements already in existence can be made to yield information of physical value, and as they are treating of different matters, there does not seem to me to be necessarily any real difference of opinion between them. While agreeing entirely with a great many of the remarks made by Sir Henry Lefroy, I believe that some common method of reduction like that proposed by Professor Stewart is necessary before we can gain any knowledge of magnetical disturbances. With regard to the proposals themselves, the principal question will always be, whether the different heads of observatories can be made to agree on a uniform plan. The exact nature of the method of reduction is a matter which has to be settled chiefly by those who have practical experience in magnetic observatories.

The method of rejecting disturbed observations, commented upon by Sir Henry Lefroy, is, no doubt, open to objection. If it was simply our object to gain information on the *mean* value of magnetic elements, no observation however much disturbed ought to be rejected; but as soon as we suspect that the *mean* value is not the *normal* value—that is to say, that disturbances act more frequently in one direction than in another—we are necessarily driven to adopt some method of rejecting disturbed observations. The objections raised by Sir Henry Lefroy against the particular method employed by Sabine seem to me to be, however, very serious, but I can see no difficulty in amending that method so as to render it free of the difficulty.

IV. *Letter from Professor G. H. Darwin, F.R.S.*

Cambridge:
June 10, 1885.

A priori I should not have thought of distinguishing between mean and normal values, but I suppose that it is desirable to do so. It is obvious that if all the observations for a month are analysed, we get the mean harmonic constituents. Then if we recompute the values with these constituents (which may be done with a tide predicter), and subtract the hourly values from the observations originally analysed, we get a series of residuals. Supposing from those residuals we arbitrarily cut out a certain number which are above some arbitrarily chosen magnitude, and submit the rest to harmonic analyses, and supposing these present us with a new series of constituents with pretty constant phases and amplitudes, then it would seem to me that we should be justified in the hypothesis that normal and mean are not the same thing. I must suppose that some process more or less equivalent to this has been carried out.

I do not observe that any proposal is made to submit the monthly constants derived from harmonic analysis to a further analysis, and thus to derive the annual, semiannual, and terannual inequalities of the con-

stituents. My meaning is that we ought to express the result in sets of terms of this form.

$$\left.\begin{array}{l} A_0 + A_1 \cos\theta + A_2 \cos 2\theta + \ldots \\ \quad + a_1 \sin\theta + a_2 \sin 2\theta + \ldots \end{array}\right\} \cos\phi$$

$$\left.\begin{array}{l} B_0 + B_1 \cos\theta + B_2 \cos 2\theta + \ldots \\ \quad + b_1 \sin\theta + b_2 \sin 2\theta + \ldots \end{array}\right\} \sin\phi$$

I had some time back a letter from Chambers at Bombay in which he says that he considers he has detected a lunar inequality. Now, unless this is certainly incorrect, is it not desirable to submit the quantities to analysis according to lunar time? I take it that your proposal as to spherical harmonic representation is to put the A_0, A_1, A_2, a_1, a_2, &c., as constants multiplied by spherical harmonic functions of the latitude and longitude of the place of observation. Gauss had, as I fancy, only considered the mean values in this way, and you are proposing to treat the diurnal inequality in a similar manner.

If much harmonic analysis is to be done, some form nearly like that used for tidal reductions would seem to be useful.

The chief complication of those forms consists in the fact that the tide-heights are taken at exact solar hours, whereas we want measurements taken also at mean lunar and a number of other kind of hours. All this is avoided in your case, unless indeed you carry out an analysis for the alleged lunar influence.

Yours sincerely,
G. H. DARWIN.

V. *Notes on the above Suggestions.* By Professor BALFOUR STEWART.

The suggestions of the Committee are invited upon the following points:

1. Do they agree with the suggestion of Dr. Schuster, that it is of importance to ascertain the solar-diurnal variation of the three magnetic elements at various stations of the earth's surface, with the view of treating these after the method of Gauss?

2. Assuming that observations made at stations near the magnetic pole need special treatment, do the Committee think with Sir Henry Lefroy that even in ordinary localities the method of Sabine is objectionable for obtaining a correct value of the solar-diurnal variation? As a good many declination observations have been treated by this method it is of importance to set the question at rest, and the suggestions of the Committee are invited as to the best means of doing this.

3. What do the Committee think of the herein-recorded method of obtaining the solar-diurnal variations in the case of the horizontal and vertical force instruments? I may state that a point of immediate scientific importance arises regarding the V. F. solar-diurnal variation, inasmuch as the observers at Lisbon and Bombay suspect that this, unlike the diurnal variations of the other two elements, does not vary with the state of the sun's surface. It would be very desirable to obtain conclusive evidence of this from other stations.

VI. *Remarks on Magnetic Reductions.* By Senhor Capello.

The method of the separation of the disturbances of the readings of the bifilar and the vertical force, of which I have sent a *résumé*, and the examples of the calculation of the last year, seems practical enough to me, although it will give some trouble. It has, however, retained the principal fault, the arbitrary nature of the quantity which constitutes the disturbance. To practise this method upon the hourly observations of the vertical force is not, I think, more difficult than upon the bifilar.

With respect to the vertical-force instrument of this observatory, I do not find it very inferior to the bifilar, except for some months on two or three occasions, during which the equilibrium position was not good, for the curves had shown a jumping motion; otherwise it has answered almost as well as the bifilar, notably in the three or four last years, where the coefficient of temperature is very much reduced by the adoption of a contrivance to compensate the effects of temperature.

Our photographs already embrace twenty-one complete years. The meteorological work, and the care connected with the administration of the observatory and the meteorological stations absorb the greater part of our time. The reductions of the magnetic observations are very much behind, and it would be difficult to advance simultaneously all the elements as they should be; therefore I think that it would be convenient to establish an agreement upon the work which by preference it is desirable to accomplish, and for what period for a general comparison. With regard to No. 7 of the suggestions of Sir J. H. Lefroy, I am entirely of his opinion, and I will add my ideas upon some researches that I think would throw light upon the causes of the disturbances.

1. In a paper by Messrs. Capello and B. Stewart ('Proc. R. S.,' January 28, 1864) upon a first comparison of the disturbances at Kew and at Lisbon, we have recognised that of the little and abrupt disturbances of three to five minutes' duration (which are called peaks and hollows), and which are seen simultaneously in the three curves, those of the declination and of the vertical force are in the same direction at Kew and in the contrary direction at Lisbon; that is to say, while the north end of the declination needle at Lisbon goes towards east the same end of the vertical-force instrument dips. The contrary happens at Kew, the north end of the declination needle going towards east, while the same end of the vertical-force raises itself.

Again, on the other hand, we have also recognised the agreement of the behaviour of the peaks and hollows of the declination curves at Kew and at Lisbon. Thus one vertical peak at Lisbon corresponds always to a hollow at Kew, and *vice versâ*. It would be interesting (1) to extend this research upon peaks and hollows further; that is to say, between more distant observatories, employing the utmost rigour possible in the time-measures, in order to recognise if the times of the appearances of the peaks are absolutely the same, or if there is a sensible difference in the most distant observatories. (2) Again, we ought to look in some observatory immediately between Lisbon and Kew in order to see if the vertical-force peaks correspond sometimes to the peaks, sometimes to the hollows of the declination.

2. For the study of the disturbances I think it would be necessary that each observatory furnished with magnetographs should make pro-

jections upon the plane perpendicular to the inclination-needle, of the movement during the disturbance of the dipping pole of such a needle supposed to be suspended without friction by its centre of gravity.[1]

This projection ought to be constructed by means of the declination variations ($\triangle d$) and those of the inclination ($\triangle i$); the first being multiplied by the cosine of the inclination ($\cos i$), in order to its reduction in the inclination direction.

The readings of the three curves being made at the time of the first meridian, chosen at intervals of 2 m., 3 m., or 5 m., according to the degree of precision which is desired, their differences are taken by comparison with the first reading, and these differences should be reduced according to the values of the coefficients. In combining the values of the movements of the vertical force and of the bifilar, we find by the known formula $\left(\triangle i = \sin i \cos i \left(\frac{\triangle Y}{Y} - \frac{\triangle X}{X}\right)\right)$ the variations of the inclination; these variations are projected upon the chart in vertical directions, having reference to the first reading, and those of the declination in horizontal directions, employing a convenient scale.

Here is an example:—Four hours of the disturbance of the 1st of February, 1881, 0 h. to 4 h. (time of Pawlowsk) at Kew, and Lisbon readings being at the intervals of five minutes.

It is noticed that all the movements are reproduced in the two figures. They are generally at great length, and now and then deformed at Kew and of different inclination by comparison with the horizontal line. All the movements at Lisbon and Kew are executed in the manner contrary to the hands of a watch. The aspect is *sooner at Kew.*

If we make a similar research upon other more distant observatories—for example, Pawlowsk and Toronto—the same movements are still remarked; but some aspects are completely deformed, the movements at Toronto being executed in the manner of the hands of a watch.

The measurements in these researches have been taken from the curves of a scheme of a study of Mr. Wild upon the disturbances of February 1, 1881.

VII. *Observations on Magnetic Reductions.* By Dr. H. Wild.

As Messrs. Balfour Stewart and Brito Capello in the 'Suggestions for the Committee on Magnetical Reductions,' as well as Herr T. P. van der Stok in the 'Communications of the International Polar Commission,' No. 109, have clearly shown, there are to be distinguished in the variations of the magnetic elements—1st, their normal daily periods; 2nd, the slow and constant changes which the absolute values of the days' means of these show; 3rd, the eventually different daily periods which

[1] I think that it would be possible to construct a very simple instrument which could well register by photography all such disturbances, which would make these researches less laborious, avoiding all the measures and reductions which are always laborious. Let a little needle be suspended conveniently by the centre of gravity, employing a thread of silk. In one point of this needle let there be a mirror perpendicular to its magnetic axis. A luminous slit might be made to fall almost perpendicularly upon the mirror, registering the movement in all the directions of the needle. In order that these movements should not be confounded and superposed, the registering cylinder should proceed by jerks from hour to hour, or oftener according to experience.

the deviations from the normal daily path show.[1] In how far we are to conceive of the two last variations as disturbances must, in my opinion, be decided by experience.

In any case we require, for the fixing and estimation of these last variations, a distinct starting point, which the normal daily path may present.

It is, therefore, specially important here to establish this normal daily path of the magnetic elements. Now regarding the method which Sabine has devised for this, and also used so much, there is, in the first place, displayed what Lefroy, Weyprecht, and others have made so prominent, the arbitrary nature of the limits which are assumed for the expulsion of the so called disturbed data. Among the different proposals which have been made for a rational fixing to these limits the most worthy of notice is that of Buys Ballot, in which these limits are to be set where the deviations begin to show another period. Van der Stok has distinctly modified the Sabine method for the discovery of the normal daily path. His altogether very complicated method suffers, in my opinion, from the same wide evils as the Sabine method, viz., that it proceeds from the daily paths, derived, like them, from the sum of all observations without distinction, i.e. including disturbances. Now it is evidently, as Weyprecht has already shown, impossible out of the so procured data to get rid altogether of the influence of the disturbances on the normal daily path, if these are not quite irregularly distributed over the day, but are all subject to a certain daily period. Lefroy again, in his working out of observations at Fort Simpson and Lake Athabasca, has not employed all the data for the deriving of the first hour's means, but only the days and hours which, according to him, were not to be regarded as disturbed, i.e. where the amplitude of the movements does not go beyond a certain limit. The fact that the exclusion of these movements is not settled through the criterion of Buys Ballot on the one hand, as well as the consideration, on the other, that days with not less amplitude of movement may also be disturbed, because the disturbed periods might unite with the normal periods, so as to weaken themselves through interference (which, as we shall see, is partly the case), prevents the method from being satisfactory. In the Programme and in the Sittings of the fourth International Polar Conference in Vienna (April 1884) I have given out and developed a new method for the derivation of the normal daily path of the magnetic elements (see 'Communications of the International Polar Commission,' No. 94, p. 199; No. 97, pp. 208, 211; No. 98, pp. 254, 255, 257, 258), which is supported by the observation that in the magnetograph traces, even at the epoch of maximum disturbances, in every month are to be found a number of days in which a quite regular, and also as regards these days concerned a recurring periodical path is distinctly recognised.

I regard these days as days with undisturbed daily paths, and the hourly means of all these days as representative of the normal daily path of the elements concerned in the month in question, according to its relative as well as to its absolute size. The selection of these normal days may from the first likewise seem very arbitrary; in practice, however, this is not the case, as hardly a doubt can arise as to which days are to be taken, and besides the result will not be very distinctly different whether one chooses one or two days more or less, if from the first one

[1] For the sake of simplicity I have spoken here only of the daily periods; clearly for the remaining periods also, which show the variations of the earth's magnetism, suitable distinctions can be made.

only takes the precaution to eliminate through linear interpolation any sudden and individual disturbances which in such days at times show themselves. The differences of all the observed data from the so obtained values of the normal daily path in each month I regard as deviations from the normal, effected by some disturbing circumstances. Should, *e.g.*, all these deviations for all hours' values be put in the form of a table, and should each be distinguished as positive and negative, either by certain signs or, according to Balfour Stewart, by different colours, we should recognise at once, from the similarity of the signs and the nearly similar size of the figures, whether a day was disturbed uniformly positive and negative, and from the recurrence of the positive figures at certain hours, and negative in certain other hours on different days, whether the disturbance points to a new period different from the normal daily periods. In order to establish these conclusions with numerical correctness, it is best to group the deviations according to their extent, separating negative and positive, and then to investigate their periodicity as Buys Ballot has proposed.

Herr D. Müller has worked out according to these principles the jottings of the magnetograph in the Observatory of Pawlowsk for the period of the International Polar Expedition, August 1882 to August 1883. His important results have been laid by me before the Imperial Academy of Science, May 21 and June 2, 1885, and are at present published in the 'Repertorium for Meteorology.' Without entering into the details of Herr Müller's results, I only remark that the success of the first attempt seems to speak well for this method. The course of the contained normal daily path in the separate months has unexpectedly become regular for all three elements—declination, horizontal and vertical intensity, and also for inclination and total intensity. The days' means of the normal days show proportionally small differences, and only the greater deviations have a pronounced different periodicity, which again is different for the positive and negative. Herr Müller has therefore only pointed out the latter as disturbances, and the former as simple oscillations about the normal path. For two months, October 1882 and March 1883, I have prepared a comparison of Sabine's method for the declination with that got by Müller from my method. Here, in the calculation according to Sabine, $\pm$ 2 is assumed as the limiting value for the expulsion of disturbances; and these operations for individual hours were repeated as often as eight times. In spite of this, there is shown by a glance at the enclosed table that even by the Sabine method the influence of the prevailing positive disturbances late in the forenoon, and of the maximum of the negative disturbances in the afternoon, could not be eliminated from the result. I have the intention to get worked out according to this new method, which, in short, is applicable to all these data, certain traces of magnetographs in St. Petersburg and later in Pawlowsk from 1870, and have for this purpose for the whole period chosen the normal days out of the photograms.

From this came the unexpected result that the number of these at the time of the minimum of the sun spots is not so much greater than at the time of the maximum.

Table referred to by Dr. Wild.

Solar-diurnal Variation of the Declination in Pawlowsk.

Göttingen time	0^h	1^h	2^h	3^h	4^h	5^h	6^h	7^h	8^h	9^h	10^h	11^h	Mid-day 12^h	13^h	14^h	15^h	16^h	17^h	18^h	19^h	20^h	21^h	22^h	23^h	
October 1882	42·9	36·6	44·5	43·5	44·4	44·3	43·4	43·1	43·1	44·6	47·0	48·1	48·2	48·6	47·2	45·8	44·1	43·7	43·8	42·6	42·2	40·7	41·5	43·0	All observations
	44·4	44·2	43·8	43·5	44·4	42·8	42·8	41·9	42·2	44·4	47·0	47·6	47·6	48·2	47·7	45·5	45·6	45·6	45·0	44·3	43·6	44·0	44·0	44·2	Normal according to Sabine
	44·1	44·1	44·1	43·8	43·8	43·6	42·7	42·0	42·3	43·7	46·3	48·4	49·0	48 8	47·5	46·7	46·6	46·5	46·1	45·3	44·9	44·7	44·3	44·3	Normal according to Wild
	+0·3	+0·1	−0·3	−0·3	+0·6	−0·8	+0·1	−0·1	−0·1	+0·7	+0·7	−0·8	−1·4	−0·6	+0·2	−1·2	−1·0	−0·9	−1·1	−1·0	−1·3	−0·7	−0·3	−0·1	Difference, Sabine—Wild
March 1883	42·2	41·5	41·4	42·1	41·5	41·7	41·7	40·7	41·0	41·6	43·7	46·7	48·7	48·4	48·5	45·7	43·0	42·9	41·3	41·4	40·6	40·4	41·1	42·1	All observations
	42·7	42·4	42·2	42·1	42·2	41·7	40·5	39·7	39·9	41·0	43·0	46·4	47·8	48·6	48·4	46·1	44·4	43·6	43·4	42·9	42·6	42·4	42·5	42·6	Normal according to Sabine
	42·6	42·7	42·5	42·1	42·1	41·9	40·7	39·0	39·3	40·1	42·5	45·3	47·7	48·3	47·1	45·6	44·6	44·3	43·7	43·4	43·2	43·1	43·5	43·0	Normal according to Wild
	+0·1	−0·3	−0·3	0·0	+0·1	−0·2	−0·2	+0·7	+0·6	+0·9	+0·5	+1·1	+0·1	+0 3	+1·3	+0·5	−0·2	−0·7	−0·3	−0·5	−0·6	−0·7	−1·0	−0·4	Difference, Sabine—Wild
Mean of both months	43·3	43·4	43·3	42·9	42·9	42·7	41·7	40·5	40·8	41·9	44·4	46·8	48·3	48·6	47·3	46·1	45·6	45·4	44·9	44·3	44·0	43·9	43·9	43·7	Normal according to Wild
	43·5	43·3	43·0	42·8	43·3	42·2	41·6	40·8	41·0	42·7	45·0	47·0	48·0	48·2	47·7	45·8	45·0	44·6	44·2	43·6	43·1	43·2	43·2	43·4	Normal according to Sabine
	+0·2	−0·1	−0·3	−0·1	+0·4	−0·5	−0·1	+0·3	+0·2	+0·8	+0·6	+0·2	−0·3	−0·4	+0·4	−0·3	−0·6	−0·8	−0·7	−0·7	−0·9	−0·7	−0·7	−0·3	Difference, Sabine—Wild

VIII. *Letter from Sir Frederick Evans to Professor Stewart.*

21 Dawson Place, Bayswater, London, W.:
May 9, 1885.

Dear Professor Balfour Stewart,—I shall be glad to render the Magnetic Committee all the assistance in my power, but I have been much out of sorts in my health for some time, and cannot so well undertake any work requiring much application.

On Tuesday I leave London for a few days, and will take the papers with me you forwarded on the 6th instant.

Until we see our way more clearly, it is the discussion of the disturbances of the Declination needle which appears to me the most important to break ground upon. On a clear insight of the probable laws at a few selected stations in both hemispheres, a discussion of other elements might well follow. Too grand a scheme and complicated methods of research would, I fear, break down. Sabine's methods had, at least, simplicity to recommend them.

A letter to the above address will reach me.

Yours faithfully,
FREDK. JNO. EVANS.

IX. *Letter from the Astronomer Royal to Professor Stewart.*

Royal Observatory, Greenwich, London, S.E.:
July 8.

Dear Prof. Stewart,—The printed suggestions for the Committee on Magnetical Reductions arrived at a very busy time, and since then I have been away from home; hence the delay.

As there is some difficulty in discussing abstract questions, I think it would save misunderstanding if you would make your suggestions with reference to our Magnetical Results for 1883, now in the press, of which I send you a copy. There are several additions and alterations which I have introduced in consultation with Mr. Ellis, in order to give as much information as practicable about the magnetic curves. We now give, in addition to mean values of the magnetic elements for each day and the mean diurnal curves for each month, the daily range, *i.e.*, the amplitude of the diurnal curve for each day, and particulars of all disturbances, small as well as large (either in the notes or in the plates). Harmonic analysis also has been applied to the diurnal variations for each month and for the year.

Now the question is, how far the suggestions of the Committee are carried out in the results given. As for rejection of disturbances, I am inclined to agree with Sir Henry Lefroy in his objection to Sabine's mode of treatment. At Greenwich the practice has been to draw a pencil curve smoothing down the irregularities of the trace, and to reject as disturbed those days for which a *continuous* pencil curve, agreeing generally in form with the normal curve, could not be drawn through the trace. I see no reason to modify this.

Yours very truly,
W. H. M. CHRISTIE.

X. *Letter from George M. Whipple, Esq., to Professor Stewart.*

Kew Observatory:

July 29, 1885.

Dear Prof. Stewart,—I have carefully read the paper you were so good as to forward to me, 'Suggestions for the Committee on Magnetical Reductions,' and must confess that I am in most points fully in accordance with Sir H. Lefroy.

I would much rather trust to the solution of the various problems of Terrestrial Magnetism by a farther and more extended series of comparison of curves than by an extension of numerical processes.

The reduction of the Fort Rae observation shows how enormously large and frequent the variations may be in some parts of the earth; and such being the case, I fail to see how any useful purpose could be served by the repetition of the calculations of Gauss.

I think that magneticians should endeavour, if possible, to enter into communication with geologists and seismologists, and endeavour to trace out clearly the causes of (what I would term) superficial variations, probably due, Prof. Schuster says, to electric currents, for localities well furnished with magnetic observatories, such as Europe, rather than to attempt at once to solve the whole problem of distribution throughout the earth of magnetic matter. I am, yours faithfully,

G. M. WHIPPLE, *Superintendent.*

P.S.—I enclose also copy of some remarks addressed by Capt. Dawson and myself to the Vienna Congress on the subject.

Further and additional remarks on the questions to be submitted to the Vienna International Polar Conference.

We are of opinion that careful inspection of the observations themselves will suffice to show the days and hours when the diurnal curve follows its normal course. From days and hours selected by this inspection, mean curves may be obtained, and ultimately by interpolation a series of hourly values may be arrived at for every day in the year.

Readings differing from these values by more than a certain separating value should be set aside and discussed as disturbances. It appears to us probable that the principle of determining the mean monthly diurnal curves for each station from observations selected only on such days as are shown by evidence of magnetographs elsewhere to have been magnetically calm, assumes beforehand a uniformity of magnetic conditions over the globe, and might, therefore, fail at certain stations. A rough comparison of Fort Rae and Kew Observatory results indicates to us that it is rather more advisable to deal with hours and not with days as a whole, and that therefore some rule, either Sabine's or Lloyd's, must of necessity be adopted.

There seems no objection to the application, first, of Lloyd's rule to throw out disturbances, and then to the subsequent classification of these disturbances after the method suggested by Wild.

We fail to see as yet any method of introducing possible corrections for sun-spot periodicity into observations made during so short an interval of time at stations where no previous observations have been taken; and therefore recommend that this disturbing element be omitted entirely

from the proposed international discussion, and left entirely to specialists for subsequent treatment.

With regard to the discussion of disturbances, we would suggest that each expedition should draw up a list of the days, selected according to Göttingen time, considered by them a disturbed day, and then from a comparison of such lists the Conference should decide on what days should be selected for particular discussion in addition to the term days.

Question 3.—Dr. Wild's suggestion as to plotting the curves is so very convenient that we have already adopted it in making preliminary curves of the Fort Rae observations. It will be necessary in addition, however, to decide upon the scale of abscissæ to be used for the 20-second interval observations on term hours. We suggest the employment of a scale giving six minutes of abscissæ to each minute of time.

Questions 4 *and* 5.—The conversion of Gaussian units into those of the C.G.S. system is so simple that it is unnecessary for the Conference to disturb the existing historic system. The Kew Observatory has already for years published their results in both systems. The foot-grain system is rapidly becoming obsolete, most magnetometers now constructed having mètre instead of foot scales.

XI. *Letter from General Lefroy to Professor Stewart.*

82 Queen's Gate, S.W.:
July 15, 1885.

My dear Professor,—I have carefully read, and return herewith, the papers of Senhor Capello and Dr. Wild. I have difficulty in attaching a physical idea to the ingenious method of projection proposed by Senhor Capello. He gives the movement, projected on a plane perpendicular to the dip of the axis or intersection of the plane of dip and the plane of declination; but I do not see how the variations of total force are to be shown in conjunction with this, or with what physical notions to connect the resulting curves. The actual realisation of the suspension of a needle by its centre of gravity without friction in any direction, especially if counterpoised to carry a mirror, would be a great achievement, but, with great respect, I doubt its being possible. Still his comparison of Lisbon and Pawlowsk is very curious, and strongly confirms my belief that, be our stations few or many, the results at *all* of them must be brought into one view, by identity of treatment and prompt circulation, to obtain a clue, and to effect this we want a *Deus ex machina.*

My file of bulletins of the International Polar Commission does not go beyond Part 5. I have not seen Herr van der Stok's communication, which Dr. Wild refers to. It has occurred to me, following a hint of Lloyd's,[1] that the *area* of movements would be a good measure of the forces producing them, and that it might be possible by an instrument on the principle of Amsler's planimeter to integrate these areas for the whole twenty-four hours, or any not very small portions of it, in moderate disturbances. The extremely active ones would not be easily measurable. To take cognisance, as has sometimes been done, of those movements only which coincide with hours of mean time or Göttingen time, appears to me to forego the special advantages of continuous record. I agree with Dr. Wild that there is no difficulty in selecting the normal days at

[1] *Trans. R.I.A.*, vol. xxii.

any station, but whether they would be the same at other stations has not, as far as I know, been ascertained. Lloyd, as you know, worked out the consequences of adopting every possible value of disturbance test. Sabine has given two or three values, all purely empirical. If my plan of *areas* were practically feasible, it does seem to me free from that objection. Dr. Wild appears to disregard magnitude, and to refer *all* the observed data to his normal values, and I think nothing less comprehensive will be found satisfactory in the long run. It is gratifying, however, to find that his results are not widely different from those obtained by Sabine's method. As Dr. Wild quotes Toronto, I suppose that some limited circulation and occasional comparison does go on, but Carpmael has no staff to keep it up regularly. We all want more hands, which means more money.

Believe me faithfully yours,
J. H. Lefroy.

XII. *Observations, &c.* By Charles Chambers, F.R.S., Superintendent, Colaba Observatory, Bombay.

There can be little doubt that the activity displayed during the last quarter of a century in the record of the phenomena of terrestrial magnetism was induced mainly by the interesting results to which Sabine was led in his discussions of the observations of the British, colonial, and other observatories; that it was in the hope of extending and completing *such* results by wider observation, that men of science in all parts of the civilised world urged upon their respective Governments the advisability of establishing magnetical observatories. Few who have studied Sabine's memoirs—displaying, amongst other remarkable generalisations, the outlines of a system of the globe in respect of the regular solar diurnal variations and the variations of these with the season of the year, and connecting with the sun-spot period variations of the range of the regular diurnal variation of declination and of the aggregate amounts of disturbance—will doubt the wisdom of the influence thus brought to bear on the guardians of the public purse, nor, whatever else may be done, of the propriety of carrying the work to the legitimate conclusion of extending and completing Sabine's results. To act otherwise, in the absence of a physical theory to which there is as yet no clue, would be to admit a change of judgment which there is nothing in the circumstances of the present day, any more than there was at the time when the work of automatic registration was initiated, to justify, and would, moreover, be to discourage the statesmen who, by the provision of funds, have aided in the production of records of the crude phenomena, from making further sacrifices in that direction: these dignitaries would, in their capacity of trustees for society, rightly complain that they had been led to expect systematised knowledge, but had been given instead piles of records of unused facts, and that the responsibility and expense of preserving these is scarcely a substitute for the reward they had been dazzled with the promise of.

2. In my opinion the scientific authorities, on whose advice much money has been spent in procuring many years' continuous records, are bound in honour to see that the representations which induced the various Governments to provide funds are justified by at least a full carrying out

of the original purposes as to the uses to which the records were to be applied.

3. The fact is that funds have been expended too exclusively upon material appliances, and upon agency for working them: the statesman can understand that his country gets a tangible return when observatory buildings, instruments, operators, records, and reports appear before him as a result of the grants that he makes; but it is for the man of science, the original adviser, to make him understand that these are very delusive results unless supplemented by appropriate measurement, computation, and discussion.

4. And this is the more important inasmuch as the cost of utilising the records, even up to the point suggested by Sabine's examples, will at least equal the amount that has been expended in their production. It is indispensable that inexpensive measuring, copying, and computing power should be used, under skilled direction, on a large scale; and here it is that the main part of the cost arises. It would be simple waste of superior energy to set a cultivated physicist to the appalling task of performing the simple but multitudinous series of operations that are involved in any adequate treatment of the observations; and it is to the insufficiency of suitable agency in the working power of existing observatories that is probably to be attributed the fact that so little has yet been done in the way of independent reduction and discussion of the records of the automatic magnetic instruments. That the work before us is laborious and costly is, however, no argument against the undertaking of it if we have reason to believe that an adequate return will be obtained; and a more costly process is to be preferred to a less costly one if the quality of the results that are the outcome of it is higher in a corresponding degree.

5. I cannot but think that the wonderful progress made during the last century in the experimental sciences is apt to make us unduly impatient of the necessarily slower progress of the observational sciences. If astronomy had, during the progress of observation, to have its period of phenomenal generalisation—its Ptolemy, its Copernicus, its Kepler—before light as to the mode of physical causation dawned upon its Newton, is it much to be wondered at that a much more complicated science, as terrestrial magnetism undoubtedly is, should have to pass through its period of discovery of general phenomenal relations—relations which the physical theory will ultimately have to explain—before the conditions essential to the conception of a general theory can be laid down?

6. It will be seen that whilst I have no faith in the flights of genius that would look at the crude facts as nature presents them to us, and from such complex data devise a theory to unravel the complexity, I have the greatest confidence in appropriate methods of analysation as leading to relatively simple phenomenal generalisations, and thence, inevitably in the long run, to the desired physical theory. The first step to be taken should, I think, be to collect together all accessible results that have already been worked out and published of the nature of—

(1) The regular solar-diurnal variations;
(2) The disturbance variations—diurnal, annual, and secular; and
(3) The lunar-diurnal variations;

and to convert the expression of them for each of the elements, declination, horizontal force, and vertical force, as far as available, into metre-gramme-second or C.G.S. units of force. If not already done, the averages of

(1) should be calculated *for each month* from the separate results of all the years that are available, and curves be constructed to represent these average monthly variations according to time-scales and force-scales which would be marked on the curve-forms. It would be convenient that the curves should appear, for any one station, in a row, beginning with January, on a long narrow slip of thick paper, so that the sets of curves for any one station might be placed close under those of any other station for easy comparison. For preservation, the slips of paper would be kept in a portfolio, not bound into a book. Curves on a less elaborate scale, as would be suggested by the meagreness (or fulness) of the materials collected, might similarly be constructed on slips to represent the variations (2) and (3). Such series of curves, to the extent to which data for them would be found easily accessible, would, I imagine, constitute a conclusive answer to those who doubt the utility of extending investigation in the same direction; but, taking continuity of change of character of the variations in passing from place to place as a criterion of the value and importance of the results obtained, they would also serve the further purpose of suggesting whether and where Sabine's methods are exact enough, or to what extent the application of even more laborious processes of reduction would be justified. These curves should be lithographed on thick slips of paper, and distributed amongst the directors of observatories and other students of terrestrial magnetism; and, as little in the shape of description or comment need accompany them, the originals could be produced by agency of an order that should be readily obtainable, and that would require but little supervision, from some specialist member of the Committee.

The curves might, with advantage, be accompanied by a table of the absolute values of the elements declination, horizontal force, and vertical force for each station; and also by tables of ranges of the solar-diurnal variations of each element on the average of each full year.

7. It has been well established by Broun and myself that the so-called lunar-diurnal variation is a function both of the season of the year and of the age of the moon, and there is reason for believing that the bulk of the phenomena is really a part of the regular solar-diurnal variation, a part that reverses its character four times in the course of the lunation.

Now the adoption, by Sabine's process, of a uniform solar-diurnal variation for the whole of a calendar month, whilst perhaps accurate enough for the determination of the general character of the disturbance laws, leaves much to be desired when the object we are in quest of is a minute variation which has, in the case of the declination, a less range than a single minute of arc, and which is subject to variation of character with change of season. Here we require that a mean solar-diurnal variation should be calculated for each individual day, in order that the elimination of mean solar effect should be nearly complete; and knowing that either a part of the solar-diurnal variation, or the bulk of the lunar-diurnal variation, runs through a cycle of change in a lunation, the best period for which to calculate the daily means is a mean lunation, or the nearest *odd* number of mean solar days to a mean lunation—that is to say, twenty-nine days. The importance of this period should be kept in view from the first, whether or not there is any immediate purpose of investigating the lunar-diurnal variations, and my present object is not so much to advocate the inclusion of such investigations in the first general scheme of operations as to explain why the period of twenty-nine days

enters into modifications that I would suggest of the procedure proposed by Dr. Balfour Stewart in dealing with the horizontal force tabulations, but which modified process should, I think, be applied also to the declination tabulations.

It is not a general rule that the hours at which the bulk of disturbance occurs are the same for both the elements declination and horizontal force; and hence—though it is highly probable that disturbance of some degree in one element occurs on the same day as disturbance of another degree in the other—we cannot with safety allot the disturbances to identical hours.

8. First, I would substitute for Sabine's classification of disturbances as 'larger' and 'smaller,' a division into those that are without the limits set by the normal ± the separating value, and those that are within those limits; and instead of rejecting disturbed observations I would, at such step of Sabine's process for separating the larger disturbances, replace each disturbed entry by the same number *minus* the disturbance without the limits—as apparent at that stage. The disturbances without the limits would be separated and the laws of their variations determined by the methods that Sabine applied to his larger disturbances, but the disturbances within the limits would remain involved with the regular variations until a late stage of the investigations.

9. Secondly, as regards progressive change in the readings, both of the declination and horizontal force instruments, it would, I think, generally suffice to treat that change as uniform during the course of a month. Having entered the hourly tabulations for a given month on a table (A call it) having the hours marked at the top of the columns and the days of the month in the first or left-hand column, and having taken daily means, I would take the mean of the first fifteen of those daily means and the last fifteen of the preceding month's table A as the mean number for the beginning of the month; and similarly the mean number for the end of the month would be the mean of the last fifteen daily means of that month and the first fifteen of the next following month. Change at the uniform rate indicated by the mean numbers[1] for the beginning and end of the month I would eliminate from the original hourly tabulations of table A, and enter the new number on a new table (B), to which I would proceed to apply Sabine's (modified) process. This would lead to a general knowledge of the regular solar-diurnal variations for each month, and of the laws of the disturbance variations; and here a resting-place might be found if it were desired to compare results from different stations before proceeding with more elaborate reductions.

10. To proceed, however, I would next, having obtained the amounts of disturbance without the limits, eliminate these amounts from the respective disturbed observations of table A, calling the table thus altered (A′), and this table should form the basis of discussion in respect of the regular solar-diurnal variations for each day, the lunar-diurnal variations, and the laws of variation of disturbances within the limits.

From table (A′), and the corresponding table of the preceding and following months, I would construct another similar table (C), each entry in which would be the 29-day mean of the numbers for the same hour

[1] The effects of disturbances without the limits on the daily means I would take to be sufficiently indicated by the departures of those means from corresponding daily means, as calculated from the mean numbers for the beginning and end of the month, with a uniform rate of change from one to the other.

in table (A′), viz., of the numbers for the day of the entry and the fourteen preceding and fourteen following days. The numbers of table C for all the hours of a given day we may take to represent very approximately the mean solar-diurnal variation—*plus* a constant—for that day, the average extending over the lunation of which that day is the middle day. They will be affected by progressive change of the values of the tabulations, and by disturbance within the limits.

11. Lastly, the excesses of the numbers of table (A′) over the corresponding numbers in table C, *plus* a constant round number,[1] should be entered on a fourth table (D). The numbers of this table, which will be affected only by that part of the solar-diurnal variation which goes through a cycle of change in a lunation, and by disturbance within the limits, we may proceed to arrange in new tables with reference to the moon's age and the season (or month) of the year,[2] and so determine the character of the variations which the luni-solar-diurnal variation is subject to. Having done this, a further elimination will put us in possession of residual numbers, the variation of which must be attributed solely to disturbances within the limits, and may be studied and the numbers be manipulated accordingly.

12. I agree with Dr. Balfour Stewart that the time has not yet arrived for laying down rules for the treatment of the vertical force tabulations.

XIII. *Letter from the Rev. Professor S. J. Perry, F.R.S.*

September 8, 1885.

Dear Dr. Schuster,—I have read over the Report Dr. Stewart kindly forwarded, and I cannot help thinking that our first step should be to collect the results already obtained for the Daily Range of the Declination, reduce the means already worked out to a common scale, and then distribute the whole in a tabular and in a graphical form. Much might be learnt from seeing these results in a collective form, and we could then better judge how far processes more laborious than those of Sir Edward Sabine are like to repay the labour.

If all observations are made use of in deducing the Daily Mean Range the Disturbance period will certainly interfere with the Solar Diurnal Range, and if we pick out quiet curves in which the Daily Range is well marked, we are very liable to give undue weight to variations in the Daily Range which are independent of ordinary disturbances.

Yours very truly,
S. J. Perry.

[1] The constant round number is added to avoid the inconvenience of having to deal afterwards with *positive* and *negative* numbers.

[2] If a separate table be allotted to each day of the moon's age, the resulting mean variations will be practically the same whether the hours refer to the solar or the lunar day; and as the numbers available are for the exact hours of the solar day, it is convenient to let the arrangement of the table be for the solar day rather than for the lunar day.

Report of the Committee, consisting of Professor CRUM BROWN (*Secretary*), Mr. MILNE HOME, Mr. JOHN MURRAY, *and* Mr. BUCHAN, *appointed for the purpose of co-operating with the Scottish Meteorological Society in making Meteorological Observations on Ben Nevis.*

DURING the past twelve months the observations on Ben Nevis have been made every hour, by night as well as by day. This remarkable continuity in the observations, conducted under such great difficulties, is due to the enthusiasm and undaunted devotion to the work evinced by Mr. Omond and his assistants, and to the completion of the Observatory building last summer with its tower, which admits of a ready egress from the Observatory when the doors are blocked with rapidly accumulating snow-drifts, except during those rare occasions, of which the winter months of 1884–85 afforded only one example, in the great storm of February, when from 6 P.M. of the 21st to 8 A.M. of the 22nd no light could be carried in a lantern outside to the instruments. This interruption refers only to the observations of the temperature of the air.

During the year the most notable additions made to the observations refer to the rainfall and the wind. The actual precipitation—rain, sleet, snow, or hail—has been collected with rain-gauges specially designed for the purpose, and measured with the greatest care every hour since June 24, 1884, with, it is believed, a very close approximation to the truth; and the hourly results for each month have been calculated.

In the end of October the anemometers designed by Professor Chrystal for the Observatory, to register continuously the velocity and direction of the wind, were added to the observing instruments. Unfortunately, however, in the colder months of the year the deposition of ice-crystals, which Mr. Omond has described in a recent paper, renders all anemometers quite useless, except at rare intervals. During the seven months from November 1, 1884, to May 31, 1885, there was only a mean of thirty days in which the anemometer was in working order. During these days the greatest velocity was on the night of April 24–25, when for twelve hours the mean velocity was seventy-four miles, rising one hour to eighty-one miles.

Estimations of wind-force have continued to be made every hour during the year, and the results show, as in the previous year, that the wind is above the mean daily force during the night and below it during the day. The maximum occurred from 2 to 3 A.M. and the minimum from 2 to 3 P.M., the difference between the extremes being between two and three miles an hour. The means of the observations made since the Observatory was opened show that the same relation holds good during each of the four seasons. These peculiarities in the diurnal variation in the velocity of the wind on Ben Nevis are of the greatest importance, especially in view of similar curves obtained at other high-level observatories situated on mountain peaks, and by Mr. Archibald Douglas from his balloon observations and experiments, and their bearing on atmospheric movements.

During July 1885 the anemometers have been continuously at work, and there are now before us a month's complete hourly records of recorded velocities and estimated wind-force. The curves drawn from

the results of these two methods are closely congruent. This double set of observations supply the data for a more exact conversion of the estimations of wind-force, according to Beaufort's scale, into their equivalents in miles. A large number of similar observations made on board the *Challenger* also form a valuable contribution to this inquiry. So far as the observations go, they appear to indicate that the equivalents in miles usually given for the higher numbers of Beaufort's scale are too small. From 8 to 9 A.M. of August 9 the anemometer registered 86 miles, and during this hour the estimated force was from 8 to 9 of the scale. The equivalent in miles for this force, provisionally adopted by the Meteorological Council, is from 48 to 56 miles. What is the number of miles when an estimated force of 10 or 11, which has been not unfrequently recorded during the colder months of the year, is reached and maintained for some time remains to be seen. Instances will in all probability occur during the autumn before the ice-deposits of the wind practically seal up the anemometer for the winter months.

The mean temperature for the year ending May 1885 was 30°·6, or 0°·3 below the calculated normal temperature given in last year's Report. The temperatures for the same period for stations in the more immediate neighbourhood were from 0°·3 to 0°·4 below their normals, being thus identical with the deviation from the normal at the Observatory. The extremes of temperature for the year were 60°·1 at 2 P.M. August 9, and 11°·1 at midnight and 1 A.M. February 16, thus giving a range of 49°·0. The coldest week yet experienced was the week ending February 21, the mean of which was 16°·2. In this week the lowest temperature for the year occurred, and the humidity fell to 22. Great dryness associated with great cold scarcely ever occurs in the weather records of the Ben, and in this case the exceptionally cold dry weather terminated with the great storm of the 21st and 22nd February already referred to.

From the observations of the maximum and minimum thermometers the mean daily range of temperature is—in winter, 6°·8; spring, 6°·4; summer, 7°·1; and autumn, 6°·6—there being thus little variation with season. From the dry bulb, there is only 0°·7 between the mean coldest and mean warmest hour of the day in winter, but in summer the difference is 3°·0. It follows that in all seasons, but particularly in winter, the changes of temperature which occur are only in a subordinate degree due to the direct influence of the sun, but are chiefly caused by the passage of cyclones and anti-cyclones over the Observatory. Indeed, it may be regarded that, in the stormy months of winter, the Ben Nevis observations present the cyclonic and anti-cyclonic changes of temperature in their simple conditions, uninfluenced by the heat of the sun.

Lower relative humidities were observed than during the previous year. On January 20, the mean of the twenty-four hours gave the very low mean humidity of 32. On the 15th of the same month, at 5 A.M., the dry bulb was 20°·9 and the wet 16°·2, which from Glaisher's tables indicates a dew-point at −16°·2 and a humidity of 19, being respectively the lowest yet noted on the top of Ben Nevis. The lowest temperature ever observed anywhere in the British Islands was −16°·0, at Springwood Park, near Kelso, in December, 1879, which closely agrees with the lowest dew-point on Ben Nevis. As regards atmospheric pressure, it is only in winter that the afternoon minimum falls below the mean daily pressure; in summer this daily minimum is 0·007 inch above the daily mean. On the top of Ben Nevis, atmospheric pressure of the three seasons, spring,

summer, and autumn, is above the daily mean for fifteen hours, from 10 A.M. to midnight, and below it for nine hours, from 1 to 9 A.M. In June, when the sun's heat is most powerful, the afternoon minimum is the least pronounced, and the diurnal curve of pressure tends towards a single maximum and minimum, similar to what occurs in the same months over the open sea in the higher latitudes. Except in mid-winter these seasonal peculiarities of the pressure are seen in the results of each month's observations, and the regularity in the changes from month to month, in the times of occurrence of the four phases of the pressure, is very striking.

The sunshine-recorder shows 464 hours of sunshine for the twelve months, which is about 11 per cent. of the possible sunshine. As regards the partition of the sunshine through the hours of the day, the most noteworthy circumstance is that during spring, summer, and autumn the amount is very considerably greater before noon than after it. As compared with the afternoon, the sunshine of the forenoon is 43 per cent. greater in spring, 50 in summer, and 33 in autumn, whereas in winter the amounts are nearly equal. During summer the maximum sunshine occurs from 6 to 9 A.M. This diminution in sunshine later in the day is no doubt caused by the ascending aerial currents which rise from the heated sides of the mountain during the warm hours of the day, and the condensation of the aqueous vapour into cloud which is the consequence.

Very heavy rainfalls are of frequent occurrence on Ben Nevis. Of single hours the largest was 1·302 inch, from noon to 1 P.M. of December 10, 1884. The largest daily fall was 4·264 inches, on December 10, 1884, a fall all but equalled by that of October 25, which was 4·231 inches. A fall of at least one inch occurs, on the average, one day in seven. Combining all the rainfall observations made since June, 1881, the following are the averages; those from July to September being for four years, June and October for three years, and November to May one year only.

	inches		inches		inches
January	7·33	May	8·37	September	9·44
February	16·94	June	8·80	October	11·08
March	12·89	July	10·70	November	19·30
April	4·85	August	11·24	December	25·20

Year, 146·14 inches.

There can be little doubt that the Ben Nevis Observatory has the largest rainfall of any place in Scotland at which a rain-gauge has hitherto been observed.

The observations at Fort William by Mr. Livingston, consisting of eye observations six times a day, and continuous records of the atmospheric pressure and temperature by a barograph and thermograph, have been regularly carried on during the year. It is not possible to over-estimate the value of these sea-level observations at Fort William, in their relations to the observations made on the top of Ben Nevis, it being from these relations that the Ben Nevis observations have their supreme importance in discussing the great problem of the weather changes of North-western Europe. This inquiry is now being carried on under the superintendence of the Directors of the Observatory.

Seventeenth Report of the Committee, consisting of Professor EVERETT, Professor Sir W. THOMSON, Mr. G. J. SYMONS, Sir A. C. RAMSAY, Dr. A. GEIKIE, Mr. J. GLAISHER, Mr. PENGELLY, Professor EDWARD HULL, Professor PRESTWICH, Dr. C. LE NEVE FOSTER, Professor A. S. HERSCHEL, Professor G. A. LEBOUR, Mr. GALLOWAY, Mr. JOSEPH DICKINSON, Mr. G. F. DEACON, Mr. E. WETHERED, *and* Mr. A. STRAHAN, *appointed for the purpose of investigating the Rate of Increase of Underground Temperature downwards in various Localities of Dry Land and under Water. Drawn up by* Professor EVERETT (*Secretary*).

THE present Report is for the two years which have elapsed since the summer of 1883.

Observations have been taken in a deep bore at Richmond, Surrey, by Mr. Collett Homersham, M.Inst.C.E., F.G.S. It is on the premises of the Richmond Vestry Waterworks, on the right bank of the Thames, and about 33 yards from high-water mark. The surface is 17 feet above Ordnance datum.

The upper part consists of a well 253 feet deep, with an internal diameter of 7 feet at top and 5 feet at bottom, which was sunk in 1876 for the purpose of supplying water to the town of Richmond, and carried down to the chalk. From the bottom of the well a 24-inch bore-hole was sunk to the total depth of 434 feet, thus penetrating 181 feet into the chalk. This portion of the work was completed in 1877. Above the chalk were tertiaries, consisting of 160 feet of London clay, 60 feet of the Woolwich and Reading beds, and some underlying sands. The water yielded at this stage was about 160 gallons a minute, and when not depressed by pumping was able to rise 4 or 5 feet above the surface. Its ordinary level, owing to pumping, was about 130 feet lower.

In 1881 the Richmond Vestry determined to carry the bore-hole to a much greater depth, and the deepening has been executed under the direction of Mr. Homersham's father, who is consulting engineer to the Vestry.

The existing bore-hole was first enlarged and straightened, to enable a line of cast-iron pipes, with an internal diameter of $16\frac{1}{2}$ inches, having the lower end driven water-tight into the chalk at a depth of 438 feet, to be carried up to the surface. The annular space surrounding this pipe served to furnish an uncontaminated supply of water to the town during the deepening.

The total thickness of the chalk was 671 feet. Below this was the upper greensand, 16 feet thick; then the gault clay, $201\frac{1}{2}$ feet thick; then 10 feet of a sandy rock, and a thin layer of phosphatic nodules. Down to this point the new boring had yielded no water. Then followed a bed $87\frac{1}{2}$ feet thick, consisting mainly of hard oolitic limestone. Two small springs of water were met with in this bed at the depths of 1,203 and 1,210 feet, the yield at the surface being $1\frac{1}{4}$ gallons a minute, with power to rise in a tube and overflow 49 feet above the ground. A partial analysis of this limestone rock showed it to contain 2·4 per cent. of

sulphide of iron in the form of pyrites. At the depth of 1,239 feet this limestone rock ended, and hard red sandstone was found, alternating with beds of variegated sandy marl or clay. After the depth of 1,253 feet had been attained, the yield of water steadily increased as the boring was deepened, the overflow at the surface being 2 gallons a minute at 1,254 feet, 8 gallons at 1,363 feet, and 11 gallons at 1,387 feet. It rose to the top of a tube carried 49 feet above the surface, and overflowed; and a pressure-gauge showed that it had power to rise 126 feet above the surface.

The diameter of the bore was $16\frac{1}{4}$ inches in the chalk, $13\frac{1}{2}$ inches in the gault, $11\frac{1}{4}$ inches in the oolitic limestone, and at the depth of 1,334 feet it was reduced to a little under 9 inches. At 1,337 feet the method of boring was changed, and instead of an annular arrangement of steel cutters, a rotary diamond rock-boring machine was employed. The bore-hole, with a diameter of $8\frac{1}{2}$ inches, was thus carried down to $1,367\frac{1}{2}$ feet, at which depth, lining tubes having to be inserted, the diameter was reduced to $7\frac{1}{4}$ inches, and this size was continued to 1,447 feet, at which depth the boring was stopped.

The bore-hole was lined with strong iron tubes down to the depth of 1,364 feet; and those portions of the tubes that are in proximity to the depths where water was struck were drilled with holes to admit the water into them. Three observations of temperature were taken at the depth of 1,337 feet, during the interval between the removal of the steel borers and the erection of the diamond boring-machine. The bore-hole was full of water, which was overflowing at the rate of from three to four gallons a minute. The thermometer employed was an inverted Negretti maximum, supplied by the secretary. In each case the temperature recorded was $75\frac{1}{2}°$ F. In the first observation, March 25, 1884, the thermometer was left for an hour and a quarter at the bottom of the bore-hole, and three weeks had elapsed since the water was disturbed by boring. The second observation was taken on March 31, when the thermometer was $5\frac{1}{2}$ hours at the bottom. In the third observation special precautions were taken to prevent convection. The thermometer was fixed inside a wrought-iron tube, 5 feet long, open at bottom. The thermometer was near the lower end of the tube, and was suspended from a water-tight wooden plug, tightly driven into the tube. There was a space of several inches between the plug and the thermometer, and this part of the tube was pierced with numerous holes to allow the escape of any cold water which might be carried down by the tube. The tube was one of a series of hollow boring-rods used in working the diamond drill-machine. By means of these it was lowered very slowly, to avoid disturbance of the water as much as possible; and the tube containing the thermometer was gradually worked through the sand at the bottom of the bore-hole. The lowering occupied five hours, and was completed at noon on Saturday, June 7.

Cement, mixed with sugar, for the purpose of slow setting, was immediately lowered on to the surface of the sand, and above this a mixture of cement and sand, making a total thickness of 3 or 4 feet of cement plugging. The thermometer was left in its place for three full days, the operation of raising being commenced at noon of Tuesday, June 10, and completed at 5 P.M. The thermometer again registered $75\frac{1}{2}°$ F., exactly the same as in the two previous observations which were taken without plugging. It would therefore appear that the steady upflow of water in

the lower part of the bore prevents any downward convection of colder water from above.

The boring has since been carried to the depth of 1,447 feet, with a diameter reduced to $7\frac{1}{8}$ inches, and Mr. Homersham made preparations for a final observation at the bottom with a plug consisting of a thick india-rubber disc covered with cement and sand; but the vestry declined to incur the responsibility of having the rods lowered again for this purpose; and as some pieces of broken lining-tube had fallen in, there would have been serious risk of jamming. Mr. Homersham accordingly contented himself with lowering the thermometer to the bottom without plugging. It remained down for six days (February 3 to 9, 1885), and gave a reading of $76\frac{3}{4}$° F. The water overflowing at the surface had a temperature of 59° F.

To deduce the mean rate of increase downwards, we shall assume a surface temperature of 50°. This gives for the first 1,337 feet an increase of $25\frac{1}{2}$°, which is at the rate of 1° F. in 52·4 feet, and for the whole 1,447 feet an increase of $26\frac{3}{4}$°, which is at the rate of 1° F. in 54·1 feet. These results agree well with the Kentish Town well, where Mr. Symons found in 1,100 feet an average increase of 1° in 55 feet.

Mr. Homersham carried on a lengthened correspondence with the secretary as to the best manner of taking the observations, and the method devised by him as above described will furnish a useful model for future observers.

Thanks are also due to the Richmond Vestry for permission to observe, and to the contractors, Messrs. Docwra, for the loan of their apparatus.

Mr. Galloway (member of the Committee) has furnished observations taken during the sinking of a shaft to the depth of 1,272 feet in or near the Aberdare valley, Glamorganshire. The name of the place is Cwmpennar, and the position of the shaft is on the slope on the east side of the valley, near the summit of the hill which separates it from the Merthyr valley. The mouth of the shaft is about 800 feet above sea level.

Observations were taken at four different depths, 546 feet, 780 feet, 1,020 feet, and 1,272 feet, the thermometer being in each case inserted, and left for twenty-four hours, in a hole bored to the depth of 30 inches, at a distance not exceeding $2\frac{1}{2}$ yards from the bottom of the shaft for the time being. About eight hours elapsed between the completion of the hole and the insertion of the thermometer. The strata consist mainly of shales and sandstone, with a dip of 1 in 12, and the flow of water into the shaft was about 250 gallons per hour.

The first of the four observations was taken in the fireclay under the Abergorkie vein; the second in strong 'clift' (a local name for arena ceous shale) in disturbed ground; the third in bastard fireclay under a small rider of coal previously unknown; the fourth in 'clift' ground two yards above the red coal vein, which overlies the 9-foot seam at a height of from 9 to 12 yards. The observations were taken by the manager, Mr. John Beith, and are as follow:

Depth in ft.	Temp. Fahr.
546	56°
780	$59\frac{1}{2}$°
1,020	63°
1,272	$66\frac{1}{2}$°

Comparing consecutive depths from 546 feet downwards, we have the following increments of temperature :—

$3\frac{1}{2}°$	in 234 ft.,	giving 1° for	67 ft.
$3\frac{1}{2}°$	„ 240 „	„	69 „
$3\frac{1}{2}°$	„ 252 „	„	72 „

—showing a remarkably regular rate of increase. A comparison of the first and fourth observations gives an increase of $10\frac{1}{2}°$ in 726 feet, which is at the rate of 1° F. in 69·1 feet. As the surface slopes about 1 in 5, and the pit is near the summit of a ridge, it is probable that in level ground of similar material the rate would be about 1° F. in 60 feet.

As a check upon this result, we find that this rate of *decrease* reckoned *upwards* from the smallest depth (546 feet) would give a surface temperature of (56 − 7·9 =) 48°·1, which, as the elevation is 800 feet, is probably very near the truth.

Mr. Garside has sent an observation of temperature taken by himself in the roof of the Mersey tunnel in August 1883. The temperature was 53°, the depth below Ordnance datum being 92 feet. A great quantity of water from the river was percolating through the sides of the tunnel.

On August 13, 1884, he verified his previous observation in Denton Colliery (15th Report). The second observation was made at the same depth as the first (1,317 feet), in the same pit and level, and under the same circumstances, except that the thermometer was allowed to remain fourteen days in the hole bored for it, instead of only six hours. The temperature observed was the same as before, namely 66°.

Mr. Garside has also supplemented his previous contribution to our knowledge of the surface temperature of the ground in the East Manchester coal-field (16th Report) by two more years' results from the same observing stations. The following are the collected results, including the year previously given :—

Croft House, in the centre of Ashton-under-Lyne, 345 *ft. above sea.*

—	4 ft. Deep	1 ft. Deep	Mean of Max. and Min. Air
1882	47°·5	46°·2	48°·4
1883	46°·6	45°·5	47°·8
1884	48°·3	47°·3	48°·9
Means	47°·5	46°·3	48°·4

District Infirmary, 501 *ft. above sea.*

—	4 ft. Deep	1 ft. Deep	Mean of Max. and Min. Air
1882	45°·9	45°·6	46°·6
1883	46°·3	45°·3	46°·3
1884	47°·7	47°·3	48°·2
Means	46°·6	46°·1	47°·0

Giving equal weight to the 4-foot and 1-foot observations, we have a mean surface temperature of 46°·9 at an elevation of 345 feet, and 46°·4

at 501 feet. The difference between them agrees well with the generally accepted rate of 1° for 300 feet, and indicates about 48° as the surface temperature at small elevations, such as 30 feet. The pits in the East Manchester coal-field from which we have observations, namely, Astley Pit (Dukinfield), Ashton Moss, Bredbury, Denton, and Nook Pit, are all sunk in ground at elevations of between 300 and 350 feet. It would therefore appear that the assumption of a surface temperature of 49°, which we made in reducing these observations, is about 2° in excess of the truth.

A very elaborate paper on Underground Temperature has recently been communicated to the Royal Society by one of the members of the Committee—Professor Prestwich. It contains probably the fullest collection that has ever been made of observations of underground temperature, accompanied in most cases by critical remarks; and adduces arguments to show that most of the temperatures observed are too low, owing to the influence of the air in mines, and of convection currents in wells. Professor Prestwich is disposed to adopt 1° F. in 45 feet as the most probable value of the normal gradient.

Report on Electrical Theories.
By Professor J. J. THOMSON, *M.A., F.R.S.*

IN this report I have confined myself exclusively to the consideration of those theories of electrical action which only profess to give mathematical expressions for the forces exerted by a system of currents, and which make no attempt to give any physical explanation of these forces; for it is evident that before we can test any theory of electrical action we must know what the actions are which it has to explain, and we cannot do this until we have a satisfactory mathematical theory. I have further limited myself to the consideration of the fundamental assumptions of each theory, and have not attempted to give any account of its mathematical developments, except in so far as they lead to results capable of distinguishing between the various theories.

I have divided the theories into the following classes :—

1. Theories in which the action between elements of current is deduced by geometrical considerations combined with assumptions which are not explicitly, at any rate, founded on the principle of the Conservation of Energy.

This class includes the theories of Ampère, Grassmann, Stefan, and Korteweg.

2. Theories which explain the action of currents by assuming that the forces between electrified bodies depend upon the velocities and accelerations of the bodies.

This class includes the theories of Gauss, Weber, Riemann, and Clausius.

3. Theories which are based upon dynamical considerations, but which neglect the action of the dielectric.

This class contains F. E. Neumann's potential theory and v. Helmholtz's extension of it.

4. C. Neumann's theory.

5. Theories which are based upon dynamical considerations, and which take into account the action of the dielectric.

This class includes the theories of Maxwell and v. Helmholtz.

We shall now proceed to the detailed consideration of these theories.

Theories in which the action between elements of current is deduced by geometrical considerations combined with certain assumptions which are not explicitly, at any rate, founded on the Principle of the Conservation of Energy.

The best known theory of this class is that of Ampère. Others, however, have been given by Grassmann, Stefan, and Korteweg, which we shall consider in order.

Ampère's Theory.

This theory was first published in 1820. In 1823 appeared his great paper, the 'Mémoire sur la Théorie Mathématique des Phénomènes Electro-dynamiques,' *Mémoires de l'Institut*, t. vi., which Maxwell describes as 'perfect in form and unassailable in accuracy,' and which at once brought the action between electric currents under the power of mathematics. Ampère founded his theory on certain postulates which he attempted to establish by experiment; inasmuch, however, as he always dealt with closed circuits in his experiments and elements of circuit in his postulates, the experimental evidence is not quite satisfactory. Ampère's experiments have been repeated by v. Ettingshausen [1] with much more delicate apparatus.

The postulates used by Ampère are as follows. The first four are given in the words of Professor Tait:—[2]

I. 'Equal and opposite currents in the same conductor produce equal and opposite effects on other conductors; whence it follows that an element of one current has no effect on an element of another which lies in the plane bisecting the former at right angles.'

II. 'The effect of a conductor bent or twisted in any manner is equivalent to that of a straight one, provided that the two are traversed by equal currents and the former nearly coincides with the latter.'

III. 'No closed circuit can set in motion an element of a circular conductor about an axis through the centre of the circle and perpendicular to its plane.'

IV. 'In similar systems traversed by equal currents the forces are equal.'

V. 'The action between two elements of current is a *force* along the straight line joining them, and proportional to the product of the lengths of the elements and the currents flowing through them.'

It follows from IV. that the force between two elements of current varies inversely as the square of the distance between them.

The assumption V. is one that can only be justified by the correctness of the results to which it leads. We have no right to assume *à priori* that the action is equivalent to a single force, and not to a force and a couple; and we have no more right to assume that the force is along the line joining the elements than we have to assume that the force between

[1] 'Ueber Ampère's elektrodynamische Fundamentalversuche,' *Wien. Ber.* (11), 77, p. 109, 1878.

[2] Tait's *Quaternions*, 2nd edit. p. 249.

two small magnets is along the line joining their centres, and in this case the assumption is untrue. It is in the nature of the assumption V. that Ampère's theory differs from others of this class. The second part of I. depends upon V. It is not true unless we assume that the force between two elements is along the line joining them.

Ampère deduces the force between two elements of current from these principles in the following way:—Suppose we have two elements of current of lengths ds_1, ds_2 traversed by currents of strengths i, j respectively. Let us take the line joining the centres of these currents as the axis of x; let the plane of ds_1 and x be taken as the plane of xy; let θ_1, θ_2 be the angles which ds_1, ds_2 respectively make with the axis of x, η the angle which the plane through ds_2 and r makes with the plane of xy.

By Ampère's second proposition the action of ds_1 on ds_2 will be the sum of the action of

$$\begin{cases} ds_1 \cos\theta_1 \text{ or } \alpha_1 \text{ along } x \\ ds_1 \sin\theta_1 \text{ or } \beta_1 \text{ along } y \end{cases}$$

on

$$\begin{cases} ds_2 \cos\theta_2 \text{ or } \alpha_2 \text{ along } x \\ ds_2 \sin\theta_2 \cos\eta \text{ or } \beta_2 \text{ along } y \\ ds_2 \sin\theta_2 \sin\eta \text{ or } \gamma_2 \text{ along } z. \end{cases}$$

Now by proposition I. α_1 cannot exert a force on either β_2 or γ_2, because it is in planes which bisect β_2 and γ_2 at right angles, so that the only component on which α_1 can exert a force is α_2. Let the force between these components be

$$\frac{a}{r^2}\alpha_1\alpha_2.$$

where r is the distance between the centres of the elementary currents.

In the same way we can show that the only component on which β_1 can exert any force is β_2. Let the force between these two elements be

$$\frac{b}{r^2}\beta_1\beta_2.$$

Thus the force between the two elements ds_1, ds_2 is

$$\frac{1}{r^2}\{a\alpha_1\alpha_2 + b\beta_1\beta_2\},$$

or, substituting for $\alpha_1\alpha_2$, $\beta_1\beta_2$ their values:

$$\frac{1}{r^2}\{a\cos\theta_1\cos\theta_2 + b\sin\theta_1\sin\theta_2\cos\eta\}\, ij\, ds_1\, ds_2.$$

The proposition III., that the action of a closed circuit on an element of current is always at right angles to the element, leads on integration to the condition

$$2a + b = 0,$$

so that the force between the two elements equals

$$\frac{a}{r^2}\{\cos\theta_1\cos\theta_2 - 2\sin\theta_1\sin\theta_2\cos\eta\}\, ij\, ds_1\, ds_2.$$

From this we are able to find the force between any two circuits or parts of circuits. To find the force on a magnetic system, Ampère used his

principle that the magnetic action of an electric current was the same as that due to a magnetic shell bounded by the circuit and magnetised to the proper intensity. In this way Ampère gave a complete theory of the action of currents upon currents and upon magnets—in fact, a complete theory of all the effects produced by a current which were known when his paper was published.

It is difficult to overrate the service which Ampère's theory has rendered to the science of electrodynamics. Perhaps the best evidence of its value for practical purposes is the extreme difficulty of finding any experiment which proves that it is insufficient. In spite of this, however, as a dynamical theory it is very unsatisfactory. If, as we are led to do by Ampère, we attach physical importance to elements of current, and regard them as something more than mathematical helps for calculating the force between two closed circuits, then we are driven to ask, not only what is the law of force between the elements, but what is the energy possessed by a system consisting of two such elements. If we do this, and find this energy by calculating the amount of work required to pull the elements an infinite distance apart, we arrive at the conclusion that the energy must depend upon the angles which the elements make with each other and with the line joining them; but if this is so, then the force between the elements cannot be along the line joining them, and there must in addition to this force be couples acting on the elements. For these reasons we see that Ampère's theory cannot give the complete action between two elements of current. What it does—and this for practical purposes is an advantage and not a disadvantage—is to give in most cases, instead of the complete action between two elements, that part of it which really affects the case under consideration.

Before discussing cases, however, in which the terms which Ampère neglects might be expected to produce measurable effects, we shall, in order to compare the various theories more easily, proceed to consider other theories of the same class.

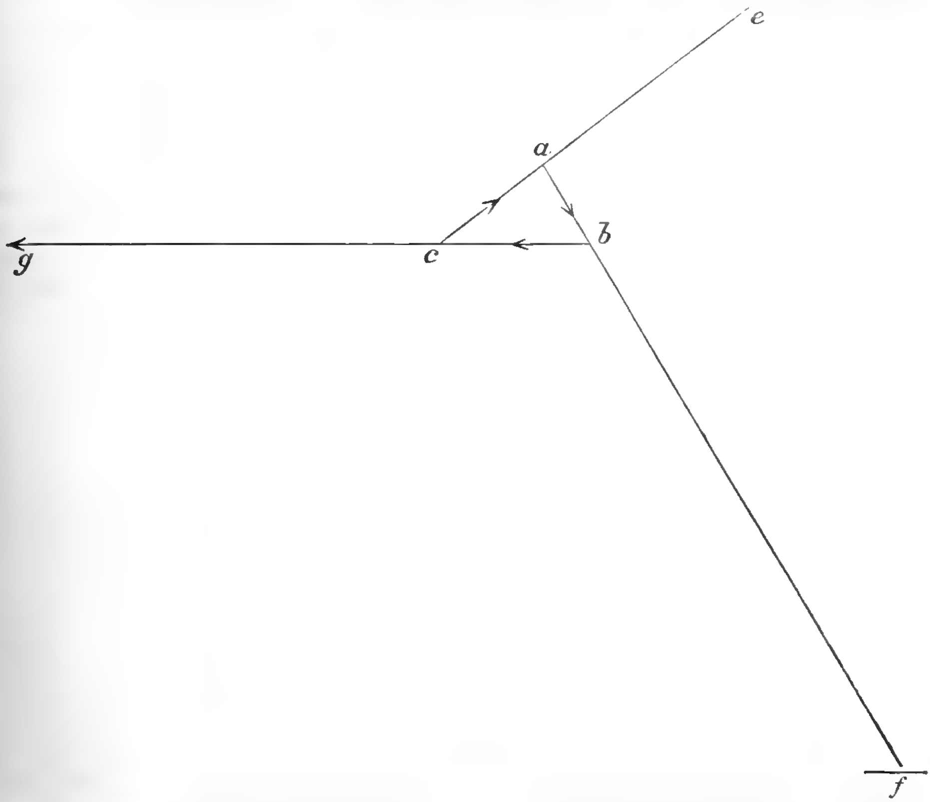
Grassmann's Theory.[1]

The method by which Grassmann obtains his theory is very remarkable. He objects to Ampère's formula for the force between two elements of current, because it makes the force between two parallel elements change from an attraction to a repulsion when the angle which the elements make with the line joining them passes through the value $\cos^{-1} 2/3$, and the object of his investigation is to get a law of force free from this peculiarity, and which, while giving the same result as Ampère's for closed circuits, shall yet be as simple as possible. He begins by regarding any circuit as built up of 'Winkelströme,' *i.e.*, currents flowing along the two infinite lines which form any angle. He points out that a circuit of any shape can be built up of such currents; the circuit *abc*, for example, may be regarded as built up of the 'Winkelströme' *eaf*, *fbg*, and *gce*.

Grassmann proceeds to calculate by Ampère's formula the action of a 'Winkelstrom' upon an element of current (a). Since the 'Winkelstrom' will have no action upon an element of current perpendicular to its plane, we see that it is only necessary to calculate its action upon the component (a') of a in its own plane. Grassmann does this by calculating the effect due to each arm of the 'Winkelstrom' separately. He

[1] Pogg. *Ann.* 64, p 1, 1845; Crelle, 83, p. 57

finds expression for the forces along and perpendicular to a', due to an infinite rectilinear current starting from a definite point. The force of such a current along a' does not depend on the angle the current makes with the line from its end to a', so that the effects of two such currents starting from the same point and flowing in opposite directions, *i.e.* of a 'Winkelstrom,' will be to produce no force along a'; thus the effect of a 'Winkelstrom' on an element of current in its own plane will be a force at right angles to the element. The force at right angles to a' due to a rectilinear current will consist of two parts, one independent of the angle made by the current with the line joining its end to the element, the other depending upon this angle. The first part will vanish when we consider a 'Winkelstrom'; the second part only will produce any effect.



Now Grassmann says that it will much simplify the analysis, and obviously (since any closed circuit may be built up of 'Winkelströme') lead, for closed circuits, to the same result as Ampère's formula, if we suppose that the law of force between elements of currents is such that the only effects produced by a rectilinear current are those which do not vanish for a 'Winkelstrom,' and hence that a straight current exerts on an element of current a force at right angles to the projection of the element on the plane containing the centre of the element and the rectilinear current, and that the magnitude of this force is

$$\frac{ij\,ds'}{r}\cot\frac{a}{2},$$

where i is the strength of the rectilinear current, j the strength of the

element of current, ds' its projection on the plane through its centre containing the straight current, r the distance of the element from the end of the straight current, and a the angle which the rectilinear current makes with the line joining its extremity to the elementary current. By taking the difference of two such rectilinear currents, Grassmann finds the action of an element (β) of current on another element (α) is a force at right angles to α', the component of α in the plane containing β and the middle point of α and equal to

$$i\,j\,\frac{d\sigma ds'}{r^2}\sin\theta,$$

where θ is the angle which β makes with r, $d\sigma$ the length of (β), and j the current flowing through it.

The direction of the force is along AB, where A is the centre of the element (α) and B the point where the normal to α' is cut by β produced *in the direction* of the current.

If we treat this theory in the same way as we did Ampère's on p. 99 by considering the action of the component α_1, β_1 of an element of current ds_1 on the components α_2, β_2, γ_2 of another element ds_2, we see that Grassmann's theory is equivalent to supposing that α_1 exerts no force on α_2, β_2, or γ_2; that β_1 exerts a force $A\beta_1\alpha_2$ on α_2 at right angles to α_2 in the plane of xy, and a force $A\beta_1\beta_2$ on β_2 at right angles to it, that is, along the line joining the element, and that it exerts no force on γ_2.

Thus we see that Grassmann's theory is equivalent to replacing Ampère's assumption, that the force between two elements of current acts along the line joining them, by the assumption that two elements of current in the same straight line exert no force on each other.

As a dynamical theory of electrodynamics, Grassmann's theory is open to the same objection as Ampère's, that it does not take into account the couples which may exist between the elements, and also to the additional objection that, according to it, the action of an element of current ds_1 on another element ds_2 is not equal and opposite to the action of ds_2 on ds_1, so that the momentum of the two elements ds_1 and ds_2 will not remain constant, and, as the theory does not take into account the surrounding ether, there is no way of explaining what has become of the momentum lost or gained by the elements. As a piece of geometrical analysis, however, the theory is very elegant and worthy of the author of the 'Ausdehnungslehre.'

From the way in which Grassmann's theory was developed we see that between closed circuits it must give the same forces as Ampère's; for unclosed circuits this is not the case, and Grassmann, at the end of the paper quoted above, mentions a case where the two theories would give opposite results, assuming that unclosed streams exist. Suppose we have a magnet ns and an unclosed current AB in the same plane as the magnet and passing through its middle point, then if Ampère's theory be true, the magnet will twist in one direction; if Grassmann's, it will twist in the opposite. This depends upon the change, according to Ampère's theory, of the force between two parallel elements from attraction to repulsion, when they make the angle with the line joining them at less than $\sin^{-1} 1/\sqrt{3}$, while according to Grassmann's theory, there is no such change.

Stefan's Theory.[1]

This resembles Ampère's theory very closely, except that Stefan does not make the assumption that the force between two elements of current is along the line joining them: this difference leads to the introduction of two forces which Ampère neglects.

We shall use the same notation as when we discussed Ampère's theory, and consider, as before, the action of an element of current ds_1 on another element ds_2. Stefan, like Ampère, assumes that we may replace an element of current by its component, so that we have to consider the action of the components (α_1, β_1) of ds_1 on the components $(\alpha_2, \beta_2, \gamma_2)$ of ds_1.

As in Ampère's theory, the component α_1 is supposed to exert a force

$$\frac{a\alpha_1\alpha_2}{r^2}$$

on α_2, this force by symmetry must be along the line joining the elements.

α_1 is supposed to exert a force on β_2 equal to

$$\frac{c\alpha_1\beta_2}{r^2}$$

along the axis of y. We can see that this force may exist, for it is conceivable that it should be in the same direction as β_2 when α_1 points from the middle of ds_1 to the middle of ds_2, and in the opposite direction to β_2 when α_1 points in the opposite direction. Stefan assumes that α_1 exerts no force on β_2 parallel to the axis of z, and no force at all on γ_2.

β_1 is supposed to exert a force on α_2 parallel to the axis of y and equal to

$$\frac{d}{r^2}\beta_1\alpha_2.$$

We may see, by the same reasoning as we used before for the force between β_1 and α_2, that it is conceivable that this force may exist. β_1 is supposed to exert no force on α_2 parallel to the axis of z.

As in Ampère's theory, β_1 is supposed to exert a force on β_2 equal to

$$\frac{b}{r^2}\beta_1\beta_2,$$

this force must by symmetry be along the line joining the elements; β_1 is supposed to exert no force on γ_2.

Thus the action of ds_1 on ds_2 consists of a force

$$\frac{1}{r^2}\left\{a\alpha_1\alpha_2 + b\beta_1\beta_2\right\}$$

along the line joining the elements, and a force

$$\frac{1}{r^2}\left\{c\alpha_1\beta_2 + d\beta_1\alpha_2\right\}$$

at right angles to this line in the plane containing ds_1 and r. If we take

[1] Stefan, *Wien. Sitzungsberichte*, 59, p. 693, 1869.

arbitrary coordinate axes and suppose that x, y, z are the coordinates of ds_1, x^1, y^1, z^1 those of ds_2, then the x component of the force on ds_2 due to ds_1 is shown by Stefan to be equal to

$$i\,j\,ds_1\,ds_2\left\{m\,\frac{d_2}{ds_1 ds_2}\,\frac{(x^1-x)}{r}+n\,\frac{d}{ds_1}\,\frac{1}{r}\,\frac{dx^1}{ds_2}+p\,\frac{d}{ds_2}\,\frac{1}{r}\,\frac{dx}{ds_1}+q\,\frac{x^1-x}{r^3}\cos\epsilon\right\}$$

with similar expressions for the force parallel to the axes of y and z.

Here i, j are the currents through ds_1, ds_2 respectively, ϵ is the angle between the elements of current, and

$$\begin{aligned} m&=-\tfrac{1}{3}\{a-b-c-d\}\\ n&=\tfrac{1}{3}\{a-b-c+2d\}\\ p&=-\tfrac{1}{3}\{a-b+2c-d\}\\ q&=\tfrac{1}{3}\{a+2b-c-d\}. \end{aligned}$$

We see from this expression for the force parallel to x that the last term is the only one which does not vanish when integrated round two closed circuits of which ds_1 and ds_2 are elements. So that the force will depend only upon q; the value of q will depend upon the units we adopt: in Stefan's work q is put equal to $-1/2$.

This is the only condition to be got by considering the translatory force between two circuits; we can get another by considering the couple acting on the closed circuit, supposed rigid, of which ds_2 forms a part. For the z component N of this couple Stefan finds the expression

$$\mathrm{N}=i\,j\,q\iint\frac{y^1x-x^1y}{r^3}\cos\epsilon\,ds_1ds_2-i\,j\,p\iint\frac{1}{r}\left\{\frac{dx^1}{ds_2}\,\frac{dy}{ds_1}-\frac{dy^1}{ds_2}\,\frac{dx}{ds_1}\right\}ds_1ds_2.$$

But supposing the two circuits to have a potential

$$i\,j\iint\frac{\cos\epsilon}{r}\,ds_1\,ds_2,$$

we can easily see that the couple

$$=i\,j\iint\frac{y^1x-x^1y}{r^3}\cos\epsilon\,ds_1ds_2-i\,j\iint\frac{1}{r}\left\{\frac{dx^1}{ds_2}\,\frac{dy}{ds_1}-\frac{dy^1}{ds_2}\,\frac{dx}{ds_1}\right\}ds_1ds_2;$$

thus if two circuits have a potential

$$p=q,$$

or substituting for p and q their values,

$$2a+b+c-2d=0.$$

If $c=0$ and $d=0$, as in Ampère's theory, this relation becomes

$$2a+b=0,$$

which is the same relation as Ampère deduced by finding the condition that the force due to a closed circuit on an element of current should be at right angles to the element, and Stefan has proved that on his theory the same condition leads to the equation

$$p=q,$$

i.e., the same condition as the one which expresses that two closed circuits have a potential.

Stefan shows that, from the consideration of the action of closed circuits on elements of other circuits or of themselves, it is impossible to get any other relation between the quantities a, b, c, d, so that we have only two relations between the quantities a, b, c, d, and thus two of them must be indeterminate.

We may give any values we please to these quantities, provided they satisfy these two relations; if we put $c = 0$, $d = 0$ we get Ampère's theory; if $a = 0$, $c = 0$, Grassmann's; and we can get a number of other theories by giving different values to these quantities.

Stefan's theory is open to the same objection as Ampère's, since it does not take into account the couples which one element may produce on another. He also limits the generality of his theory by supposing that the force between two elements of currents in one plane is in that plane.

Korteweg's Theory.[1]

According to this theory, the forces between two elements of current are the same as in Stefan's theory; Korteweg, however, considers in addition the couples which one element may produce on another.

If we use the notation we adopted in discussing Stefan's theory, we have, considering the force on ds_2, a force

$$\frac{1}{r^2}\{a\alpha_1\alpha_2 + b\beta_1\beta_2\}$$

along the line joining the elements, and a force

$$\frac{1}{r^2}\{c\alpha_1\beta_2 + d\alpha_2\beta_1\}$$

parallel to the axis of y.

In addition to these forces, Korteweg supposes that from the action of α_1 on β_2 there is a couple whose axis is parallel to the axis of z equal to

$$f\alpha_1\beta_2,$$

and from the action of α_1 on γ_2 a couple on γ_2 whose axis is parallel to the axis of y and equal to

$$-f\alpha_1\gamma_2;$$

from the action of β_1 on α_2 there is a couple on α_2 whose axis is parallel to the axis of z and equal to

$$g\beta_1\alpha_2,$$

and from the action of β_1 on γ_2 there is a couple on γ_2 whose axis is parallel to the line joining the elements and equal to

$$h\beta_1\alpha_2.$$

If we now take arbitrary co-ordinate axes, the forces on the element ds_2 are the same as those given by Stefan's theory. The couples, however, are different. The component parallel to the axis of x of the couple on ds_2 is given by the equation

$$\mathrm{L} = \left[\frac{d}{r^2}\,\frac{dr}{ds_2}\left(y\frac{dz}{ds_1} - z\frac{dy}{ds_1}\right) - \frac{a-d-c}{r^3}\,\frac{dr}{ds_2}\,\frac{dr}{ds}\,(y^1z - z^1y)\right.$$

[1] Crelle, xc. p. 49, 1881.

$$- \frac{b}{r^2} \frac{d^2r}{ds_1 ds_2} (y^1z - z^1y) - \frac{c}{r^2} \frac{dr}{ds_1} \left(z \frac{dy^1}{ds_2} - y \frac{dz_1}{ds_2} \right)$$

$$+ \frac{(h+g)}{r} \frac{dr}{ds_1} \left\{ (y^1 - y) \frac{dz_1}{ds_2} - (z^1 - z) \frac{dy^1}{ds_2} \right\}$$

$$+ \frac{h-f}{r} \frac{dr}{ds_2} \left\{ (y^1 - y) \frac{dz}{ds_1} - (z^1 - z) \frac{dy}{ds_1} \right\}$$

$$- h \left\{ \frac{dy^1}{ds_2} \frac{dz}{ds_1} - \frac{dy}{ds_1} \frac{dz}{ds_2} \right\} \Bigg] ii\, ds_1\, ds_2,$$

with similar expressions for the components of couple around the axes of y and z.

By making the force between two closed circuits have the same value as that given by Ampère's theory, Korteweg finds that

$$a + 2b - d - c = -3A^2,$$

where A is a constant quantity whose value depends upon the unit of current adopted.

By making the couples produced by one closed circuit on another have the same value as that given by Ampère and the potential theory, he finds that

$$\frac{d}{dr}(r^2h) + (g-h)r - c + 2A^2 = 0.$$

Korteweg considers that the experiments of v. Ettingshausen, quoted above, prove (1) that the force on an element of circuit produced by a closed circuit is at right angles to the element, and (2) that the couple on an element due to a closed circuit has the value given by Ampère's theory. The first condition gives

$$c - b = 2A^2;$$

the second the two conditions

$$\frac{d}{dr}(rh) - f = 0$$

$$h + g = 0.$$

And he points out that we cannot get any more conditions by considering the action between two closed circuits, or the action of a closed circuit on an element of another.

It should be noticed that since, according to this theory, part of the action of one element of a circuit on another consists of a couple, the condition that the force due to a closed circuit on an element of another should be at right angles to the element is not, as in Stefan's theory, identical with the condition that the expression for the couple exerted by one closed circuit on another should be the same as that given by Ampère.

This theory is valuable because it is the most general one of the class we are considering which has been published. It is the only one which takes into account the couples, and by giving special values to the quantities a, b, c, d, f, g, h, we can get any of the other theories of this class.

On the theories which explain the action of currents by assuming that the forces between two electrified bodies depend upon the velocities and accelerations of the bodies.

According to these theories a body conveying an electric current contains equal quantities of positive and negative electricity, so that it will not exert any ordinary electrostatic effect: the positive electricity is supposed, however, to be moving differently from the negative. In some of the theories (Weber's, Gauss's, Riemann's) Fechner's hypothesis, that the electric current consists of positive electricity moving in one direction (the direction of the current), and an equal quantity of negative electricity moving at the same speed in the opposite direction, is assumed; in other theories (Clausius') only one of the electricities is supposed to move, the other remains at rest. We can see in a general way how the assumption that the forces between two electrified particles depend on the velocities and the accelerations of the particles can explain the effects produced by an electric current.

Let us take first the mechanical action between two circuits A and B, and let us consider the action of an element (a) of A on an element (b) of B. We shall consider first the action of the two electricities which are flowing through a on the positive electricity which is flowing through b. Since the motion of the positive electricity in a relative to that of the positive electricity in b is not the same as the motion of the negative electricity in a relative to that of the positive in b, the forces due to the positive and negative electricities in a will not counterbalance, so that there will be a resultant force on the positive electricity in b depending on the inequality between the motion of the positive and negative electricities in a relative to that of the positive in b. Similarly there will be a force on the negative electricity in b depending on the inequality between the velocities of the positive and negative electricities in a relative to that of the negative in b, and, except for special laws of force and special values of the velocities of the electricities in b, this force will not be equal and opposite to the force on the positive electricity in b, so that a mechanical force on b will be produced by the currents through a.

Let us now consider how inductive forces can be explained by this hypothesis: let us suppose that the element a is moving, and that the element b is at rest. The velocity of the electricity in a will be the resultant of the velocity with which the electricity flows through a and the velocity of translation of a itself, so that since the velocities of flow of the positive and negative electricities are different, the actual velocity of the positive electricity will differ in magnitude from the velocity of the negative (unless, assuming Fechner's hypothesis, the element a is moving at right angles to itself); thus the force due to the positive electricity in a on a unit of positive electricity at b will not be equal and opposite to that due to the negative electricity in a, and thus there will be an E.M.F. at b due to the motion of a. This explains induction due to the motion of the primary circuit.

Let us now consider induction due to the variation of the intensity of the current in the primary circuit. According to all the theories there is a force produced by a moving electrified body proportional to the first power of the acceleration of that body. Let us consider the elements a and b again, and suppose that a variable current is flowing through a and no current through b; then if we suppose that a variation in the intensity

of a current is accompanied by an alteration in the velocity of flow, the acceleration of the positive electricity will, if we take Fechner's hypothesis, be equal and opposite to that of the negative; but since there is a part of the force due to the moving electrified body which changes sign both with the electrification and the acceleration, the force due to the acceleration of the positive electricity will be equal in all respects to that due to the acceleration of the negative, so that there will be a resultant force on a unit of positive electricity at b, and this force is the electromotive intensity at b due to the alteration of the intensity of the current in a. In this way we can explain the induction due to the variation of the current in the primary circuit.

Theories of this kind have been given by Gauss, Weber, Riemann, and Clausius, and these writers have given expressions for the force between two electrified particles moving in any way. We shall afterwards consider these expressions in detail, but we may remark in passing that the theories of Gauss, Weber, and Riemann have much in common; among other things they all lead to impossible results. In addition Clausius has shown that, unless we make Fechner's hypothesis about a current, viz. that it consists of equal quantities of positive and negative electricity moving with equal speeds in opposite directions, a current would on these theories exert a force on an electrified body at rest.

The question of the forces due to moving electrified bodies is interesting in connection with electrolysis. Taking the ordinary view that the current is carried by the ions, we know from Hittorf's researches that the anion and the cation move at different rates, so that the forces produced by these will be different; hence we should expect an electrolyte conveying a current to exert a force on a charged particle at rest.

We shall now go on to consider the various theories separately.

Gauss's Theory.[1]

Gauss assumes that the force between two particles separated by a distance r and charged with quantities of electricity e and e' is along the line joining the particles and equal to

$$\frac{ee'}{r^2}\left\{1+\frac{1}{c^2}\left\{u^2-\frac{3}{2}\left(\frac{dr}{dt}\right)^2\right\}\right\}$$

where u is the relative velocity of the two particles and c is a constant. This law will, if we make Fechner's hypothesis, explain the mechanical force between two circuits; but, since it contains no term depending on the acceleration, it cannot explain the E.M.F. produced by the variation of the strength of the current in the primary; it is also inconsistent with the principle of the Conservation of Energy, and so we need not consider it any further.

W. E. Weber's Theory.[2]

Weber assumes that the force between two charged particles, using the same notation as before, is

$$\frac{ee'}{r^2}\left\{1+\frac{1}{c^2}\left(r\frac{d^2r}{dt^2}-\tfrac{1}{2}\left(\frac{dr}{dt}\right)^2\right)\right\}$$

[1] Gauss's theory was published after his death in his collected works, Göttingen edition, vol. v. p. 616. See also Maxwell's *Electricity and Magnetism*, 2nd edit. vol. ii. p. 440.

[2] Weber's theory was published in 1846 in *Abhandlungen der Königlich-Säch-*

This formula is not inconsistent with the principle of the Conservation of Energy; making Fechner's hypothesis, it will explain the mechanical force between circuits conveying currents; it will also explain induction due both to the motion of the primary and the alteration in the strength of the current in the primary. We shall see, however, that it makes a body under certain circumstances behave as if its mass were negative; *i.e.* if it were acted on by a force in a direction opposite to that in which it is moving, its velocity would continually increase.

Riemann's Theory.

This is explained in his 'Schwere Electricität und Magnetismus,' edited by Hallendorff, p. 327. According to this theory the force between two electrified bodies is not altogether along the line joining them, but consists of the following parts:—

1. A force along the line joining the particles equal with the same notation as before to

$$\frac{ee'}{r^2}\left\{1+\frac{u^2}{c^2}\right\}$$

2. A force on the first particle parallel to its velocity relative to the second equal to

$$-\frac{2ee'}{c^2r^2}u\frac{dr}{dt}.$$

3. A force on the first particle parallel to its acceleration relative to the second equal to

$$\frac{2ee'}{c^2r}f,$$

where f is the relative acceleration of the particles.

There are of course similar forces acting on the second particles, and we see from the form of the expressions of the forces that the force on the first particle is equal and opposite to the force on the second. Riemann's law of force is not inconsistent with the principle of the conservation of energy, and it explains the mechanical force between two circuits; hence it must explain the induction of currents. We shall see, however, that it is open to the same objection as Weber's theory, viz. that it makes an electrified particle under certain circumstances behave as if its mass were negative.

Clausius' Theory.[1]

If x, y, z are the co-ordinates of the first electrified particle, x', y', z' those of the second, then according to this theory the x component of the force on the first particle is equal to

$$-ee'\left[\frac{d}{dx}\left\{(1-v\,v'\cos\epsilon/c^2)\frac{1}{r}\right\}-\frac{1}{c^2}\frac{d}{dt}\left(\frac{1}{r}\;\frac{dx'}{dt}\right)\right]$$

With similar expressions for the components parallel to y and z, here

sischen Gesellschaft der Wissenschaften, 1846, p. 211; it is reprinted in *Electrodynamische Maassbestimmungen*, 1871. A good account of the theory is given in Maxwell's *Electricity and Magnetism*, 2nd edit. vol. ii. chap. xxiii.

[1] This theory is given in Crelle, vol. 82, p. 85. There is also a full abstract in Wiedemann's *Beiblätter*, vol. i. p. 143.

v and v' are the velocities of the first and second particles respectively, and ϵ is the angle between their directions of motion. We may analyse these forces a little differently, and say that the force on the first particle consists of—

1. A force along the line joining the particles equal to

$$\frac{ee'}{r^2}\left\{1-vv'\cos\epsilon/c^2\right\}$$

2. A force parallel to the velocity of the *second* particle and equal to

$$\frac{ee'}{c^2r^2}\frac{dr}{dt}v'.$$

3. A force parallel to the acceleration of the *second* particle equal to

$$-\frac{ee'}{c^2r}\frac{dv'}{dt}.$$

We have, of course, corresponding expressions for the force on the second particle.

Clausius' formulæ differ from those of Gauss, Weber, and Riemann in two very important respects.

1. They make the forces between two electrified bodies depend on the absolute velocities and accelerations of the bodies, while the others make them depend only on the relative velocities and accelerations.

2. They do not make the forces between the bodies equal and opposite, so that the momentum of the system does not remain constant.

These results show that if this theory is true, we must take the ether surrounding the bodies into account. The first result can then be explained by supposing that the velocities which enter into the formulæ are the velocities of the bodies relatively to the ether at a considerable distance from the bodies, and the second result by supposing that the ether possesses a finite density, and that the momentum lost or gained by the bodies is added to or taken from the surrounding ether.

The case is analogous to the case of two spheres A and B moving in an incompressible fluid; in this case the forces on the sphere A depend on the velocities and accelerations of B relatively to the fluid at a great distance from the sphere, and are independent of the velocity and acceleration of A; the forces are not equal and opposite, and the momentum lost or gained by the system is added to or taken from the momentum of the fluid. At the end of this section we shall see that, if we assume that variations in what Maxwell calls the electric displacement produce effects analogous to those produced by ordinary conduction currents, we get the same forces between moving electrified bodies as are given by Clausius' theory.

Clausius' theory is not inconsistent with the principle of the conservation of energy, and we shall see that it does not lead to the same difficulty as the theories of Weber and Riemann, viz., that under special circumstances a body would behave as if its mass were negative.

Assuming that in an electric current we have equal quantities of positive and negative electricity moving with different velocities, Clausius has shown in the paper already cited that his theory gives Ampère's results for the mechanical force between two circuits, and the usual

expression for the induction due to the motion of the primary circuit, or variation in the strength of the current passing through it.

Fröhlich[1] urges against Clausius' law that since, according to it, an electric current in motion exerts an electromotive force on a moving electrified particle, even though the particle is moving at the same rate as the circuit, every current on the earth's surface ought to exert an electromotive force on an electrified particle relatively at rest, since each is moving with the velocity of the earth. This force is one that can be derived from a potential, so that the integral of the force taken round a closed curve would vanish, and thus, even if this result were true, two circuits would not induce currents in each other if they were relatively at rest. Budde[2] points out, however, that the moving circuit would exert an electromotive force at each point of itself, and thus cause a separation of the electricity in the circuit, so that it would get coated with a distribution of electricity, the electrostatic action of which would balance that due to the action due to its motion on a point relatively at rest. The velocities which enter into Clausius' formulæ are velocities relative to the ether, so that if the ether moves with the earth, an electric current will, according even to this theory, exert no electromotive force on a point relatively at rest, and there will be no electrification on the surface of the circuit. The velocity c which occurs in all these theories is a velocity comparable with the velocity of light.

General Considerations on these Theories.[3]

We shall now go on to discuss a general way of treating theories of the kind we have been considering. Perhaps the best way of doing this is to consider not the forces between the electrified bodies, but the energy possessed by them. If the energy depends on the electrification there will be forces between two electrified bodies. Now the potential energy depends on the electrification, and this dependence produces the ordinary electrostatic forces between two electrified bodies at rest. If, however, the kinetic energy as well as the potential depends on the electrification, then the forces between two electrified bodies in motion will be different from the forces between the same bodies at rest. An easy way of seeing this is by means of Lagrange's equations.

If T be the kinetic energy, and x a co-ordinate of any kind, then we have, by Lagrange's equations,

$$\frac{d}{dt}\frac{d\mathrm{T}}{d\dot{x}}-\frac{d\mathrm{T}}{dx}=\text{external force of type } x.$$

Hence if we have any term T′ in the expression for the kinetic energy, we may, if we like, regard it as producing a force equal to

$$-\frac{d}{dt}\frac{d\mathrm{T}'}{d\dot{x}}+\frac{d\mathrm{T}'}{dx}.$$

A simple illustration of this is afforded by the centrifugal force. In

[1] Fröhlich, *Wied. Ann.*, ix. p. 277, 1880.

[2] *Wied. Ann.*, x. p. 553, 1880.

[3] See Clausius 'On the Employment of the Electrodynamic Potential for the Determination of the Ponderomotive and Electromotive Forces,' *Phil. Mag.*, 1880, v. 10, p. 255.

the expression for the kinetic energy of a moving particle there is the term

$$\tfrac{1}{2}mr^2\,\dot{\theta}^2,$$

where r is the distance of the particle from some fixed point, and θ the angle which the radius from this point to the particle makes with some fixed line; m is the mass of the particle. This term, by the above rule, will give rise to a force of type r, *i.e.*, along the radius vector equal to

$$mr\dot{\theta}^2,$$

and this is the ordinary centrifugal force.

Now let us consider a moving electrified body. If it is symmetrical, and moves in an isotropic dielectric, it is evident that the electrification, if it enters at all, can only enter as a factor of the total velocity q, and cannot affect the separate components of the velocity differently.

Let us suppose that the body is charged with a quantity of electricity denoted by e, then the kinetic energy, if it depends on the electrification, must be of the form

$$\tfrac{1}{2}mq^2 + f(e)q^2,$$

where $f(e)$ denotes some function of e. Now $f(e)$ must be always positive, for if it were negative we could make

$$\tfrac{1}{2}m + f(e)$$

negative, and then the electrified body would behave like one of negative mass. The simplest form satisfying this condition which we can take for $f(e)$ is αe^2, where α is some positive constant; so that the form of expression for the kinetic energy may be taken as

$$(\tfrac{1}{2}m + \alpha e^2)q^2.$$

Now let us go on to the case where we have two electrified bodies present, with charges e and e' of electricity; let m and m' be their masses, q, q' their velocities, of which the components parallel to the axes of x, y, z are (u, v, w), (u', v', w') respectively, the co-ordinates of the particles being (x, y, z), (x', y', z').

If everything is symmetrical, the expression for the kinetic energy, if it only involves second powers of the charges of electricity, will be of the form

$$\tfrac{1}{2}mq^2 + \tfrac{1}{2}mq'^2 + \alpha e^2q^2 + \beta e'^2\,q'^2 + ee'\,\kappa\,.\,f\,\{u, v, w, u', v', w'\}$$

where $f\,(u, v, w, u', v', w')$ is a quadratic function of u, v, w, u', v', w'.

By Lagrange's equations we see that the last term will give rise to a force parallel to the axis of x on the particle whose charge is e equal to

$$\kappa ee'\left\{\frac{df}{dx} - \frac{d}{dt}\frac{df}{du}\right\},$$

with similar expressions for the forces parallel to y and z. We can see, by substituting in this expression, that we get Weber's law if we make

$$f = \frac{1}{r}\left\{\frac{x - x'}{r}(u - u') + \frac{y - y'}{r}(v - v') + \frac{z - z'}{r}(w - w')\right\}^2;$$

Riemann's law, if we make

$$f=\frac{1}{r}\{(u-u')^2+(v-v')^2+(w-w')^2\};$$

Clausius' law, if we make

$$f=\frac{1}{r}\{uu'+vv'+ww'\};$$

and that we cannot get Gauss's law in this way; this is in accordance with the fact that Gauss's law does not satisfy the principle of the conservation of energy. This way of considering the theories enables us to see that neither Weber's nor Riemann's formulæ can be right, for if they were, an electrified body, when in presence of another, would, under certain circumstances, behave as if its mass were negative. Thus take Weber's law as an example: let us suppose that two electrified bodies are moving along the line joining them, which we may take as the axis of x; then the expression for the kinetic energy, putting in the value of f which corresponds to Weber's law, is

$$\tfrac{1}{2}mq^2+\tfrac{1}{2}mq'^2+\alpha e^2q^2+\beta e'^2q'^2+\frac{\kappa ee'}{r}\{q-q'\}^2,$$

so that if

$$\tfrac{1}{2}m+\alpha e^2+\frac{\kappa ee'}{r}$$

be negative, then the coefficient of q^2 in the kinetic energy will be negative, and the body will behave as if its mass were negative; and, by sufficiently increasing e' or diminishing r, we can make this expression negative, so that Weber's law leads to results which are inconsistent with experience. This result of Weber's law was first pointed out by Helmholtz.[1]

Exactly the same objection applies to Riemann's theory, and indeed we see that it will apply to any theory which makes the force between two electrified bodies depend on *relative* velocities and accelerations.

The same objection need not apply to Clausius' theory, for substituting the value of f belonging to his theory, the kinetic energy equals

$$(\tfrac{1}{2}m+\alpha e^2)q^2+(\tfrac{1}{2}m'+\beta e'^2)q'^2+\kappa ee'\,\frac{qq'\cos\epsilon}{r},$$

so that the kinetic energy will be always positive if

$$(\tfrac{1}{2}m+\alpha e')\ \ (\tfrac{1}{2}m'+\beta e'^2)>\frac{\kappa^2e^2e'^2\cos^2\epsilon}{4r^2}.$$

This condition will evidently be satisfied if

$$\alpha\beta>\frac{\kappa^2}{4r^2},$$

and this relation does not involve the electrification. We cannot assume that we can make r so small that this condition is not satisfied, for r has a minimum value depending upon the shape and size of the electrified bodies. For example, if these are spheres, r cannot be less than the sum of their radii. On the other hand, α and β may be functions of the

[1] *Ueber die Theorie der Elektrodynamik.* Crelle, vol. lxxv. p. 535; Collected Works, Bd. 1, S. 647.

sizes of the electrified bodies, and the geometrical relations may be such that the condition written above must be always satisfied.

Physical reasons why the force between two electrified bodies should depend on their velocities and accelerations.

If we assume Maxwell's hypothesis that a change in the electric polarisation produces the same effect as an electric current, then we see that the kinetic energy of an electrified body must be different from the kinetic energy of the same body moving at the same rate but not electrified. For let us suppose that we have an electrified body at rest, and consider the amount of work necessary to start it with a velocity q. It is evident that it will be greater than when it is not electrified, for when it is electrified and in motion the electric polarisation in the surrounding dielectric will be in changing, and so in addition to starting the body with a velocity q we have, if Maxwell's hypothesis be true, to establish what is equivalent to a field full of electric currents. The production of these currents of course requires work, so that more work is required to start the body with a velocity q when it is electrified than when it is not; in other words, the kinetic energy of a moving electrified body is greater than that of one not electrified, but under similar conditions as to mass and velocity. In fact in this case electricity behaves as if it possessed inertia.

In a paper published in the 'Philosophical Magazine,' April 1881, I have shown that the kinetic energy of a charged sphere of radius a and mass m moving at a velocity q

$$= \tfrac{1}{2}mq^2 + \tfrac{2}{15}\frac{e^2\mu}{a}q^2,$$

where μ is the magnetic permeability of the surrounding dielectric and e the charge on the sphere. If there are two spheres in the field, then I have shown in the same paper that the kinetic energy

$$= \tfrac{1}{2}mq^2 + \tfrac{2}{15}\frac{\mu e^2}{a}q'^2 + \tfrac{1}{2}m'q'^2 + \tfrac{2}{15}\frac{\mu e'^2}{a'}q'^2 + \tfrac{1}{3}\frac{\mu ee'}{\mathrm{R}}qq'\cos\epsilon,$$

where corresponding quantities for the two spheres are denoted by plain and accented letters. We see from this expression that the forces between the spheres are exactly the same as those given by Clausius' formulæ. It would not, however, be legitimate to go and develope the laws of electrodynamics from this result in the way that Clausius does, as Clausius' conception of an electric current does not accord with that of the displacement theory. We may remark that in this case the part of the kinetic energy due to the electrification is always positive.

On theories which are based on dynamical considerations, but which neglect the action of the dielectric.

F. E. Neumann[1] was the first to develope a theory founded on the principles of the Conservation of Energy. His theory was based upon the assumption that two elements of circuit ds, ds', traversed by currents ι, ι' possess an amount of energy equal to

$$\mathrm{A}^2\frac{\iota\,\iota'\cos\epsilon}{r}\,ds\,ds',$$

[1] 'Die mathematischen Gesetze der inducirten electrischen Ströme,' *Schriften der Berliner Academie der Wissensch.*, 1845.

where A is a constant which depends upon the unit of current, r is the distance between the elements, and ε the angle between their directions. F. E. Neumann showed that this assumption leads to the same law of force between two closed circuits as that given by Ampère, and also explained by means of it the induction of electric currents. v. Helmholtz [1] has investigated the most general expression for the energy possessed by two elements of current which is consistent with the condition that the force between two closed circuits should be the same as that given by Ampère's theory. We shall consider this theory in detail, as it includes all theories of this class, and we shall wish to refer to it when we come to discuss the relative merits of the various theories. v. Helmholtz begins by showing that the most general expression for the energy of two elements of circuit consistent with Ampère's laws for closed circuits is

$$\tfrac{1}{2}\,\frac{A^2\,\iota\,\iota'}{r}\,\{(1+k)\cos\varepsilon + (1-k)\cos\theta\cos\theta'\}\,ds\,ds',$$

where θ and θ' are respectively the angles ds and ds' make with the line joining the elements, k is a constant, and the other symbols have the same meaning as before.

Let us call this quantity T; then we know that T denotes the existence of a force $d\text{T}/dr$ or

$$-\tfrac{1}{2}\,\frac{A^2\,\iota\,\iota'}{r^2}\,\{(1+k)\cos\varepsilon + (1-k)\cos\theta\cos\theta'\}\,ds\,ds'$$

along r, and a force $-d\text{T}/rd\theta$ at right angles to r in the plane of ds and r, and in such a direction that it tends to diminish θ; this force equals

$$\tfrac{1}{2}\,\frac{A^2\,\iota\,\iota'}{r^2}(1-k)\left(\sin\theta\cos\theta' + \cos\theta\sin\theta'\,\frac{d\theta'}{d\theta}\right);$$

and since

$$\frac{d\theta'}{d\theta} = \cos\eta,$$

where η is the angle between the plane containing r and ds and that containing r and ds', the transverse force

$$= \tfrac{1}{2}\,\frac{A^2\,\iota\,\iota'}{r^2}(1-k)\,\{\sin\theta\cos\theta' + \cos\theta\sin\theta'\cos\eta\}.$$

We see that these forces will coincide with those assumed in Korteweg's theory if the quantities a, b, c, d, which occur in that theory, have the following values:

$$\begin{aligned} a &= -A^2 \\ b &= -\tfrac{1}{2}(1+k)\,A^2 \\ c &= \tfrac{1}{2}(1-k)\,A^2 \\ d &= \tfrac{1}{2}(1-k)\,A^2. \end{aligned}$$

So that whatever be the value of k, these quantities satisfy the condition

$$2a + b + c - 2d = -3A^2.$$

[1] Crelle, lxxii. p. 57; *Gesammelte Werke*, vol. i. p. 545.

According to Stefan, it is necessary if two circuits have a potential that

$$2a + b + c - 2d = 0.$$

But Stefan did not consider the couple exerted by one element of circuit on another. The couples acting on the element ds' will be as follows. There will be a couple tending to increase θ', *i.e.* a couple whose axis is at right angles to both ds' and r, equal to $dT/d\theta'$, *i.e.* to

$$\tfrac{1}{2}\,\frac{A^2\,\iota\,\iota'}{r}\{(1+k)\sin\theta\cos\theta'\cos\eta - 2\cos\theta\sin\theta'\},$$

and another couple tending to increase η, *i.e.* a couple whose axis is along the line joining the elements equal to $dT/d\eta$, *i.e.* to

$$-\tfrac{1}{2}\,\frac{A^2\,\iota\,\iota'}{r}(1+k)\sin\theta\sin\theta'\sin\eta.$$

We see that these will agree with the couples in Korteweg's theory of

$$f = -\frac{A^2}{r}; \qquad g = -\tfrac{1}{2}A^2\,\frac{(1+k)}{r}; \qquad h = \tfrac{1}{2}A^2\,\frac{(1+k)}{r}.$$

Let us return to the consideration of the energy of the circuits, and suppose that, instead of currents flowing along linear circuits, we have a distribution of them throughout space. If u, v, w be the currents in the element dx, dy, dz, then the part of the energy contributed by this element will be

$$-A^2\,\{Uu + Vv + Ww\}\,dx\,dy\,dz,$$

where

$$U = \tfrac{1}{2}\iiint\left\{(1+k)\frac{u}{r} + (1-k)\frac{x-\xi}{r^2}\,\{u(x-\xi) + v(y-\eta) + w(z-\zeta)\}\right\}d\xi\,d\eta\,d\zeta,$$

with symmetrical expressions for V and W, where

$$r^2 = (x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2.$$

We may write the expressions for U, V, W in the form

$$U = \tfrac{1}{2}(1-k)\frac{d\psi}{dx} + \iiint\frac{u}{r}\,d\xi\,d\eta\,d\zeta$$

$$V = \tfrac{1}{2}(1-k)\frac{d\psi}{dy} + \iiint\frac{v}{r}\,d\xi\,d\eta\,d\zeta$$

$$W = \tfrac{1}{2}(1-k)\frac{d\psi}{dz} + \iiint\frac{w}{r}\,d\xi\,d\eta\,d\zeta,$$

where $\psi = \iiint\left(u\,\frac{dr}{d\xi} + v\,\frac{dr}{d\eta} + w\,\frac{dr}{d\zeta}\right)d\xi\,d\eta\,d\zeta$

If u, v, w are the components of the ordinary conduction current, e the volume density of the free electricity, then

$$\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} = -\frac{de}{dt};$$

and if l, m, n be the direction cosines of the normal to a surface at which

the currents become discontinuous, σ the surface density of the electricity on this surface, then

$$l\,(u-u^1) + m\,(v-v^1) + n\,(w-w^1) + \frac{d\sigma}{dt} = 0.$$

Remembering these equations, ψ may be transformed into

$$\iiint r\,\frac{de}{dt}\,dx\,dy\,dz + \iint r\,\frac{d\sigma}{dt}\,ds\,;$$

or if ϕ denote the electrostatic potential of the free electricity, we see

$$\psi = -\frac{1}{2\pi}\iiint \frac{1}{r}\,\frac{d\phi}{dt}\,dx\,dy\,dz.$$

Substituting this value of ψ we find

$$\nabla^2\mathrm{U} = (1-k)\frac{d^2\phi}{dx\,dt} - 4\pi u,$$

$$\nabla^2\mathrm{V} = (1-k)\frac{d^2\phi}{dy\,dt} - 4\pi v,$$

$$\nabla^2\mathrm{W} = (1-k)\frac{d^2\phi}{dz\,dt} - 4\pi w.$$

We also see that

$$\frac{d\mathrm{U}}{dx} + \frac{d\mathrm{V}}{dy} + \frac{d\mathrm{W}}{dz} = -k\frac{d\phi}{dt}.$$

In order to get the equations connecting the electromotive force with the variation of the electrodynamic potential, Neumann made use of Lenz's law, and assumed that, since by that law the electromotive force tending to increase the current in an element of circuit moving with a velocity w in the direction s would be of the same sign as

$$-\mathrm{X}w,$$

where X is the force along s on the element per unit of length per unit of current flowing through it, it was actually equal to this quantity multiplied by a constant c, *i.e.* to

$$-c\mathrm{X}w\,;$$

but if Ti ds be the energy of the element of current whose length is ds, and current strength i,

$$\mathrm{X} = \frac{d\mathrm{T}}{ds},$$

and

$$w = \frac{ds}{dt}\,;$$

so that the electromotive force per unit of length of the element

$$= -c\,\frac{d\mathrm{T}}{ds}\,\frac{ds}{dt}$$

$$= -c\,\frac{d\mathrm{T}}{dt}.$$

v. Helmholtz has shown that it follows from the principle of the Conservation of Energy that if the energy in the elements dx, dy, dz, traversed by currents u, v, w, be

$$A^2 (Uu+Vv+Ww)\, dx\, dy\, dz,$$

then the components of the electromotive force parallel to the axes x, y, z respectively, due to the variation in the electrodynamic potential, will be

$$-A^2\frac{dU}{dt},\ -A^2\frac{dV}{dt},\ -A^2\frac{dW}{dt};$$

the free electricity produces an electromotive force whose components are

$$-\frac{d\phi}{dx},\ -\frac{d\phi}{dy},\ -\frac{d\phi}{dz},$$

so that the total electromotive force parallel to x, y, z

$$=-\frac{d\phi}{dx}-A^2\frac{dU}{dt}.$$

Now if σ be the specific resistance of the conductor, σu equals the electromotive force parallel to the axis of x, so that

$$\sigma u=-\frac{d\phi}{dx}-A^2\frac{dU}{dt};$$

so that by the preceding equations

$$\frac{\sigma}{4\pi}\left\{\nabla^2 U-(1-k)\frac{d^2\phi}{dx\,dt}\right\}=-\frac{d\phi}{dx}-A^2\frac{dU}{dt},$$

with similar equations for V, W. The quantities U, V, W and their first differential coefficients with respect to x, y, z are continuous, and these equations enable us to find them if we know the value of ϕ, the potential of the free electricity. Helmholtz shows that the whole energy in the field due to the currents may be written

$$\frac{A^2}{8\pi}\iiint\left\{\left(\frac{dU}{dy}-\frac{dV}{dz}\right)^2+\left(\frac{dV}{dz}-\frac{dW}{dy}\right)^2+\left(\frac{dW}{dy}-\frac{dU}{dz}\right)^2+k\left(\frac{d\phi}{dt}\right)^2\right\}dx\,dy\,dz,$$

so that if k be negative, this expression may become negative, and in that case the equilibrium would be unstable; hence we conclude that only those theories are tenable for which k is positive.

The equations written above are those which hold in a conductor, in an insulator the equations are

$$\nabla^2 U=(1-k)\frac{d^2\phi}{dx\,dt}$$

$$\nabla^2 V=(1-k)\frac{d^2\phi}{dy\,dt}$$

$$\nabla^2 W=(1-k)\frac{d^2\phi}{dz\,dt}$$

$$\nabla^2\phi=0.$$

v. Helmholtz shows that in the conductor the electrostatic potential ϕ satisfies the equation

$$\nabla^2\left\{\phi+\frac{\sigma}{4\pi}\frac{d\phi}{dt}\right\}=A^2 k\frac{d^2\phi}{dt^2},$$

so that if the conductor has an infinitely small resistance, the equation becomes

$$\nabla^2\phi = A^2 k \frac{d^2\phi}{dt^2}.$$

This represents a wave motion, the velocity of propagation of which is $1/A\sqrt{k}$. If k, as in Neumann's theory, be equal to unity, then the velocity of propagation is $1/A$, and from the value of A, found from experiments on the force between circuits conveying currents, this is nearly equal to the velocity of propagation of light. Thus, according to Neumann's theory, in a perfect conductor an electrostatic disturbance is propagated with the velocity of light. In an insulator ϕ satisfies the equation

$$\nabla^2\phi = 0;$$

and this represents a motion propagated with an infinite velocity, and thus, according to this theory, an electrostatic disturbance is propagated with an infinite velocity in a perfect non-conductor. In an imperfectly conducting substance the velocity of propagation of a wave motion would depend upon the length of the wave.

Let us now go on to consider, what, according to this theory, are the forces acting on an element of circuit conveying a current. Let us suppose that the element ds forms an element of a circuit through which a current ι is flowing; then the energy of the circuit will be

$$A^2\int \iota\ \left\{U\frac{dx}{ds} + V\frac{dy}{ds} + W\frac{dz}{ds}\right\} ds.$$

In order to find the force parallel to x, let us suppose that each element of the circuit receives an arbitrary displacement x, parallel to the axis of x; then the alteration in the energy will be

$$A^2\int \iota\ \left\{\frac{dU}{dx}\frac{dx}{ds} + \frac{dV}{dx}\frac{dy}{ds} + \frac{dW}{x}\frac{dz}{ds}\right\}\delta x\, ds + A^2\int \iota\, U\ \frac{d\,.\delta x}{ds}\, ds.$$

Integrating the second term by parts, we see that it may be written

$$[A^2\iota U\delta x] - A^2\int \iota\ \left\{\frac{dU}{dx}\frac{dx}{ds} + \frac{dU}{dy}\frac{dy}{ds} + \frac{dW}{dz}\frac{dz}{ds}\right\}\delta x\, ds.$$

Substituting this value for the second term, we see that the alteration in the energy,

$$= [A^2\iota U\delta x] + A^2\int \iota\ \left\{\frac{dy}{ds}\left(\frac{dV}{dx} - \frac{dU}{dy}\right) - \frac{dz}{ds}\left(\frac{dU}{dz} - \frac{dW}{dx}\right)\right\}\delta x\, ds;$$

hence we see by the Conservation of Energy that there is a force on each element of current parallel to the axis of x, equal to

$$\iota\left\{\frac{dy}{ds}\left(\frac{dV}{dx} - \frac{dU}{dy}\right) - \frac{dz}{ds}\left(\frac{dU}{dz} - \frac{dW}{dx}\right)\right\}A^2,$$

and by symmetry forces parallel to y and z equal respectively to

$$\iota\left\{\frac{dz}{ds}\left(\frac{dW}{dy} - \frac{dV}{dz}\right) - \frac{dx}{ds}\left(\frac{dV}{dx} - \frac{dU}{dy}\right)\right\}A^2;$$

$$\iota\left\{\frac{dx}{ds}\left(\frac{dU}{dz} - \frac{dW}{dx}\right) - \frac{dy}{ds}\left(\frac{dW}{dy} - \frac{dV}{dz}\right)\right\}A^2$$

so that the resultant of these forces is at right angles to the element. In addition to these forces there are other forces at places where the quantity ιU is discontinuous, or, since U is continuous, at places where ι is discontinuous, whose components parallel to the axes of x, y, z, are respectively

$$A^2U\partial\iota,\ A^2V\partial\iota,\ A^2W\partial\iota;$$

but $\partial\iota$ equals de/dt, the rate at which the free electricity is increasing at the place, so that we have at any place where the free electricity is changing a force whose components are

$$A^2U\frac{de}{dt},$$
$$A^2V\frac{de}{dt},$$
$$A^2W\frac{de}{dt}.$$

We saw before that the force acting on the circuit per unit length is at right angles at each point to the element of circuit at that point, so that, unless a circuit includes places at which the quantity of free electricity is changing, the circuit will behave as if it were acted on by forces which were everywhere normal to the elements on which they act. In the experiments which have been made to test whether the force on the element is at right angles to it, there have been no points where the free electricity is changing, so that these experiments do not contradict Neumann's theory, although, according to it, the force on an isolated element is not necessarily at right angles to that element, for in addition to the forces normal to the element we have forces equal to $A^2U\,de/dt$, $A^2V\,de/dt$, $A^2W\,de/dt$ parallel to x, y, z respectively, acting at the ends, the resultant of these two forces is a force whose components parallel to the axes of x, y, z are respectively

$$\frac{A^2\,de\,dU\,ds}{dt\ ds},$$
$$\frac{A^2\,de\,dV\,ds}{dt\ ds},$$
$$\frac{A^2\,de\,dW\,ds}{dt\ ds},$$

and as these forces are not necessarily at right angles to the element, the resultant force is not necessarily so; the effect of these forces could not, however, be detected unless there was a discontinuity in the current.

v. Helmholtz in the memoir[1] which we have already quoted shows that, according to his extension of F. E. Neumann's theory, the forces between two elements of circuit ds and ds' may be looked upon as made up of—

(1) A repulsive force on ds due to an end of ds', equal (per unit length) to

$$-A^2\iota\frac{de'}{dt}\frac{1}{r}\frac{dr}{ds};$$

[1] *Ueber die Theorie der Elektrodynamik*, dritte Abhandlung, Crelle, lxxviii. pp. 273, 324, 1874; *Gesammelte Werke*, p. 723.

(2) A repulsive force on ds due to ds', equal per unit length to

$$-\frac{A^2\iota'}{r^2}\left\{2\cos(ds\,ds') - 3\cos(r\,ds)\cos(r\,ds')\right\};$$

(3) A repulsion between the ends of ds and ds', equal to

$$-\frac{1}{2}(1+k)\,A^2\frac{de}{dt}\frac{de'}{dt};$$

(4) A repulsion on ds', due to an end of ds equal per unit length to

$$-A^2\iota'\frac{de}{dt}\frac{1}{r}\frac{dr}{ds}.$$

The second of these is the only one considered in Ampère's theory. We must remember in calculating these forces that each element has two ends.

Let us now go on to find the couples acting at each point of the circuit. If the tangent to the circuit makes an angle θ with the axis of z, and the plane containing the tangent and the axis of z an angle ϕ with the plane of xz, then we may write

$$\frac{dx}{ds} = \sin\theta\cos\phi,$$

$$\frac{dy}{ds} = \sin\theta\sin\phi,$$

$$\frac{dz}{ds} = \cos\theta,$$

so that with the same notation as before the energy equals

$$A^2\int\iota\left(U\frac{dx}{ds} + V\frac{dy}{ds} + W\frac{dz}{ds}\right)ds$$

$$= A^2\int\iota\,(U\sin\theta\cos\phi + V\sin\theta\sin\phi + W\cos\theta)\,ds,$$

so that if ϕ increase by $\delta\phi$, the alteration in the energy equals

$$A^2\int\iota\,(-U\sin\theta\sin\phi + V\sin\theta\cos\phi)\,\delta\phi\,ds,$$

so that the couple tending to increase ϕ, *i.e.* the couple whose axis is parallel to the axis of z, equals

$$A^2\iota\,(V\sin\theta\cos\phi - U\sin\theta\sin\phi)$$

per unit length of current; this may be written

$$A^2\iota\left(V\frac{dx}{ds} - U\frac{dy}{ds}\right),$$

hence the couples parallel to the axes of y and x are by symmetry respectively

$$A^2\iota\left\{U\frac{dz}{ds} - W\frac{dx}{ds}\right\},$$

$$A^2\iota\left\{W\frac{dy}{ds} - V\frac{dz}{ds}\right\}.$$

The axis of the resultant couple is perpendicular to the element and to the vector whose components are U, V, W.

In another paper[1] v. Helmholtz discusses the force acting per unit of volume on a conductor traversed by electric currents; he shows that, according to the potential theory, if u, v, w are the components of current through an element $dx\,dy\,dz$, and X, Y, Z the components of the force acting on this element of volume per unit of volume, then

$$\mathrm{X}=\mathrm{A}^2\left[v\left(\frac{d\mathrm{V}}{dx}-\frac{d\mathrm{U}}{dy}\right)+w\left(\frac{d\mathrm{W}}{dx}-\frac{d\mathrm{U}}{dz}\right)+\mathrm{U}\frac{de}{dt}\right]$$

$$\mathrm{Y}=\mathrm{A}^2\left[u\left(\frac{d\mathrm{U}}{dy}-\frac{d\mathrm{V}}{dx}\right)+w\left(\frac{d\mathrm{W}}{dy}-\frac{d\mathrm{V}}{dz}\right)+\mathrm{V}\frac{de}{dt}\right]$$

$$\mathrm{Z}=\mathrm{A}^2\left[u\left(\frac{d\mathrm{U}}{dz}-\frac{d\mathrm{W}}{dx}\right)+v\left(\frac{d\mathrm{V}}{dz}-\frac{d\mathrm{W}}{dy}\right)+\mathrm{W}\frac{de}{dt}\right]$$

He then discusses the application of the potential law to sliding contacts, that is, contacts such as those made by a wire dipping into mercury; in the derivation of the forces from the potential law it is assumed that the displacements are continuous, and it might be objected that we have no right to apply the law in this case as the motion of the wire and the mercury seems at first sight discontinuous. v. Helmholtz, however, points out that, as the wire carries the mercury with it as it moves, the motion is not really discontinuous and that Neumann's law is applicable. The question of sliding contacts comes prominently forward when we compare the various theories; we shall return to it again in this connection.

v. Helmholtz also in this paper investigates the electromotive forces acting on a conductor in motion; he shows that if the components of the velocity of the conductor at any point are α, β, γ, then P, Q, R, the components of the electromotive force, are given by the equation

$$\mathrm{P}=\beta\left(\frac{d\mathrm{U}}{dy}-\frac{d\mathrm{V}}{dx}\right)+\gamma\left(\frac{d\mathrm{U}}{dz}-\frac{d\mathrm{W}}{dx}\right)+\frac{d}{dx}(\mathrm{U}\alpha+\mathrm{V}\beta+\mathrm{W}\gamma),$$

with similar equations for Q and R.

He also investigates the difference between the results of Ampère's and Neumann's theory for the E.M.F. due to induction. The results are complicated; for practical purposes it is sufficient to notice that when there is a mechanical force tending to make the body move in a certain direction, there must be an E.M.F. when the body moves in that direction.

C. Neumann's Theory.

C. Neumann assumes that the electric potential energy is propagated with a finite velocity, and that if two electrified bodies are in motion, the mutual potential energy is not ee'/r, where r is the distance between them, but ee'/r', where r' is the distance between them at a time t before, where t is the time taken by the potential to travel from the one body to the other.

The energy considered in C. Neumann's theory is a kind of energy quite different from any that we have experience of; it is not poten-

[1] *Ueber die Theorie der Elektrodynamik*, Crelle, lxxviii. pp. 273–324, 1874; *Gesammelte Werke*, vol. ii. p. 703.

tial energy, because that at any time depends only on the position of the system at that time; it is not kinetic, because that depends only on the position and velocity of the system at the time under consideration, whilst Neumann's energy depends on the velocity and position of the system at some previous time. In spite of all this, however, Neumann applies the ordinary dynamical processes to this energy just as if it were kinetic or potential; and in this way arrives at the same expression as Weber for the force between two moving electrified bodies. The rest of the theory is the same as Weber's, except that Neumann's assumption about the nature of a current is different from Weber's. According to Weber, an electric current consists of equal quantities of positive and negative electricity, moving with equal velocities in opposite directions. According to Neumann, the positive electricity alone can move, the negative being attached to the molecules of the conductor. Riecke and Clausius have shown that with this assumption and Weber's law a steady current must exert a force upon a particle at rest and charged with electricity, and must in consequence produce an irregular distribution of electricity over any conductor in its neighbourhood.

Theories which are founded on dynamical considerations and which take into account the action of the dielectric.

In the theories we have hitherto considered, the influence of the medium which exists between the currents has been left altogether out of account. In the theories which we shall now proceed to discuss, the influence of this medium is taken into consideration. This is, perhaps, the most important step that has ever been made in the theory of electricity, though from a practical point of view it is comparatively of little importance; in fact, for practical purposes almost any one of the preceding theories will satisfy every requirement.

Faraday was the first to look upon the dielectric as an important agent in electrical phenomena; he was led to this by his desire to get rid, as far as possible, of the idea of action at a distance, which was so prevalent in his time, but to which his researches have given the death-blow. In his 'Experimental Researches,' § 1164, speaking of electrostatic induction, he says, 'I was led to suspect that common induction itself was in all cases an action of contiguous particles, and that electrical action at a distance (*i.e.* ordinary inductive action) never occurred except through the influence of surrounding matter.' And later on he gives his views as to the nature of the effect in the medium; in § 1298 of the 'Researches' he says, 'Induction appears to consist in a certain polarised state of the particles into which they are thrown by the electrified body sustaining the action, the particles assuming positive and negative points or parts, which are symmetrically arranged with respect to each other and the inducting surfaces or particles. This state must be a forced one, for it is originated and sustained only by force, and sinks to the normal or quiescent state when that force is removed. It can be continued only in insulators by the same portion of electricity, because they only can retain this state of the particles.' He gives an experimental illustration of his view in § 1350. He says, 'As an illustration of the condition of the polarised particles in a dielectric under induction I may describe an experiment. Put in a glass vessel some clear rectified

oil of turpentine, and introduce two wires passing through glass tubes, when they coincide with the surface of the fluid and terminating in balls or points. Cut some very clean dry white silk into small particles, and put these also into the liquid; then electrify one of the wires by an ordinary machine and discharge by the other. The silk will immediately gather from all parts of the liquid and form a band of particles reaching from wire to wire, and if touched by a glass rod will show considerable tenacity; yet the moment the supply of electricity ceases the band will fall away and disappear by the dispersion of its parts. The conduction by the silk is in this case very small, and after the best examination I could give to the effects, the impression on my mind is that the adhesion of the whole is due to the polarity which each filament acquires, exactly as the particles of iron between the poles of a horse-shoe magnet are held together in one mass by a similar disposition of forces. The particles of silk therefore represent to me the condition of the molecules of the dielectric itself, which I assume to be polar, just as that of the silk is. In all cases of conductive discharge the contiguous polarised particles of the body are able to effect a neutralisation of their forces with greater or less facility, as the silk does also in a very slight degree. Further we are not able to carry the parallel, except in imagination; but if we could divide each particle of silk into two halves, and let each half travel until it met and united with the next half in an opposite state, it would then exert its carrying power (1307), and so far represent electrolytic discharge.'

And it is not only in statical electricity that Faraday recognised the importance of the dielectric. When he is discussing his discovery of the induction of currents, which he ascribes to the assumption of what he called the electrotonic state by the body in which induced currents are developed, he says, § 73, 'It may even exist in non-conductors,' that is, that there is an electromotive force acting on the surrounding dielectric due to the variation in the primary current. Again, in § 1661, he says, 'Now though we perceive the effects only in that portion of matter which, being in the neighbourhood, has conducting properties, yet hypothetically it is probable that the non-conducting matter has also its relations to, and is affected by, the disturbing causes, though we have not yet discovered them. Again and again the relation of conductors and non-conductors has been shown to be one, not of opposition in kind, but only in degree (1334, 1603); and therefore for this, as well as for other reasons, it is probable that what will affect a conductor will affect an insulator also, producing, perhaps, what may deserve the term of the electrotonic state (60, 242, 1114).' And though he was unable to detect these effects experimentally, the following paragraph (1728) shows that his belief in their existence was not shaken: 'But then it may be asked, What is the relation of the properties of insulating bodies, such as air, sulphur, or lac, when they intervene in the line of magnetic action? The answer to this is at present merely conjectural. I have long thought there must be a particular condition of such bodies, corresponding to the state which causes currents in metals and other conductors (26, 53, 191, 201, 213); and considering that the bodies are insulators, one could expect that state to be one of tension. I have, by rotating non-conducting bodies near magnetic poles, and poles near them, and also by causing powerful electric currents to be suddenly formed and to cease around and about insulators in various directions, endeavoured to make some

such state sensible, but have not succeeded. Nevertheless as any such state must be of exceedingly low intensity, because of the feeble intensity of the currents which are used to induce it, it may well be that the state may exist, and may be discoverable by some more expert experimentalist, though I have not been able to make it sensible.'

Maxwell was the first to express Faraday's ideas in mathematical language. In his papers on 'Physical Lines of Force' in the 'Philosophical Magazine' for March, April, May, 1861, and January, February, 1862, he developes a theory of electricity according to which the energy of the electro-magnetic field resides in the dielectric as well as in the conductors; later, in the 'Philosophical Transactions' for 1865, he greatly extended Faraday's ideas as well as put them into definite mathematical language, and this without reference to any special theory of the mechanism which produces electrical phenomena. We shall devote some time to discussing Maxwell's theory, as it is freer from serious objections than any other, while at the same time it covers a much wider ground.

We shall begin by referring to Maxwell's view of the state of the dielectric in the electric field. Maxwell supposes that the dielectric is changed, and perhaps the clearest way of describing this change is that of Faraday in the extract already quoted. Maxwell's nomenclature as to this change is a little unfortunate; instead of speaking, like Faraday, of the polarisation of the dielectric, he speaks of the change as consisting of an electric displacement, which in isotropic media is in the direction of the electromotive force. Mathematically the two things are identical; we may either say of a wire that it is negatively electrified at one end A, and positively at the other end B, or else that there is a displacement of positive electricity from A to B, so that there is an excess of positive electricity at B and a deficiency at A. But though the words in a mathematical sense are identical, still the word displacement seems to connote special qualities which limit the generality of the conception in an undesirable way; the word displacement seems to imply motion in the direction of displacement, while polarisation only implies that there is a vector change of some kind in the dielectric. The condition of the dielectric is quite analogous to the state of a piece of soft iron placed in a magnetic field. The polarisation or displacement is in isotropic media in the direction of the electromotive force and proportional to it, just as the magnetic induction in isotropic media is in the direction of the magnetic force and proportional to it. It was this proportionality combined with the fact that as soon as the electromotive force is removed the dielectric springs back, as it were, to its original state, that led Maxwell to use the word displacement. He looked on the case as analogous to that of an elastic solid, which springs back to its original position when the external force is removed, and in which the displacement is proportional to the impressed force. To avoid any unnecessary definiteness we shall use the term dielectric polarisation instead of electric displacement. Thus according to this view the dielectric in the electric field is polarised. This polarisation means change of structure of some kind, and to produce this change of structure work is required. The energy in the polarised dielectric will be greater than the energy when it was unpolarised, for if the energy were less the dielectric would go into the polarised condition of itself, without the application of any external forces.

It is rather difficult to see what is meant in Maxwell's theory by the phrase 'quantity of electricity.' According to the old two-fluid theory

an electrified body was supposed to contain a certain quantity of something called electricity, rules were given for measuring this quantity, and the phrase 'quantity of electricity' meant something quite definite. In Maxwell's theory, where everything is referred to the dielectric, the meaning of the phrase is not so obvious. We can, however, arrive at some idea of what is meant by the consideration of what are called 'tubes of force.' Let us suppose at first that the dielectric is air. A line of force is a line whose direction at any point coincides with the direction of the electromotive force at that point, so that we may conceive the electric field to be filled with lines of force. If we consider the lines of force passing through some small closed curve, they will form a tube, and such a tube is called a tube of force; and if the dimensions of the tube are such that the product of the cross section at any point and the electromotive force at that point is constant and equal to 4π, the tube is called a unit tube. We may thus conceive space to be filled with unit tubes of force. Since the electromotive force inside a conductor vanishes these tubes will end at the surface of a conductor. And the quantity of electricity on the conductor will be equal to the excess of the number of lines of force which leave the conductor over those which enter it. A tube is said to leave the conductor when the direction of the electromotive force is along the normal drawn outwards, and to enter it when the direction of the electromotive force is along the normal drawn inwards. As the conductor moves about it may be supposed to carry the tubes of force along with it, so that the number of tubes which end on the conductor remains constant. This way of looking at electrification is quite satisfactory as long as we keep to one dielectric air; when we have to consider different dielectrics it requires modification, because the electromotive force changes abruptly as we pass from one dielectric into another, so that a tube which was a unit tube in one dielectric is not so in another. It is easy, however, to extend the definition of unit tubes so as to meet this difficulty; for if the tubes pass from one dielectric A into another B the ratio of the product of the cross section and electromotive force is constant for all the tubes and depends only on the nature of the dielectrics; this ratio is the ratio of the specific inductive capacities in B and A. Air is taken as the standard dielectric, and the specific inductive capacity of another dielectric A is the ratio of the product of the electromotive force and cross section of a tube in air to the product of the same quantities for the same tube in the dielectric A. Thus if we amend our definition and say that a circuit tube is one such that the product of the cross section, the electromotive force, and the specific inductive capacity of the medium in which the cross section is situated is equal to 4π, then the quantity of electricity on a conductor is equal to the excess of the number of unit tubes which leave the conductor over the number of those which enter it. In this way we get an idea of what is meant by 'quantity of electricity' in Maxwell's theory. Maxwell accounts for the forces observed between electrified bodies by a system of stresses in the dielectric separating them; as, however, at present we wish to compare Maxwell's theory with other theories which do not touch upon this point, we shall discuss this part of the theory separately later on and go on to discuss those points which are involved in all the theories.

The next great point in Maxwell's theory is the development of Faraday's remark that the electrotonic state may exist even in non-conductors, *i.e.*, that the dielectric surrounding a changing current is acted

on by electromotive forces which polarise it. This statement is one as to whose truth nobody seems to entertain any doubt, whilst the statement that changes in the dielectric polarisation produce effects analogous to those produced by ordinary conduction currents is by no means so universally received, and yet the one seems the necessary consequence of the other. If we regard the whole electric field as a dynamical system, and to fix our ideas consider an element a of the dielectric, and the current, which is supposed to vary, then, since a variation in the current polarises a, *i.e.*, produces a change in its structure, there must be mechanism connecting the current with the element a; but if this is so then it follows from dynamical principles that a non-uniform variation in the structure of a must produce a change in the current—in other words, that a change in the rate of change of the polarisation of a produces an electromotive force on the current, *i.e.* that the change of polarisation produces an effect analogous to that of an ordinary conduction current. We may illustrate this by a purely dynamical example. Suppose we have a dynamical system defined by two co-ordinates p and q, and let T be the kinetic energy of the system and V the potential energy; then by Lagrange's equation the force tending to increase q

$$= -\frac{dV}{dq} + \frac{dT}{dq} - \frac{d}{dt}\frac{dT}{d\dot{q}}.$$

Now if there is a force tending to alter q which depends upon the acceleration of p, there must be a term in the kinetic energy of the form

$$A\dot{p}\dot{q};$$

but if we apply Lagrange's equations to the p co-ordinates we see that this term implies the existence of a force tending to increase p equal to

$$-\frac{d}{dt}A\dot{q},$$

so that an acceleration of q will produce a force tending to alter p. To make this applicable to the case of the current and the dielectric, we have only to suppose that $\dot{p}$ represents the current, q the polarisation of the dielectric. That a change in $\dot{p}$ produces a change in q is shown by the fact that the dielectric is polarised when the current is changing, and this shows that there must be a term of the form $A\dot{p}\dot{q}$, in expression for the kinetic energy; from this it follows that a change in $\dot{q}$, *i.e.*, in the rate of change of the polarisation, will produce an E.M.F. on the circuit. As the variation of the dielectric polarisation produces the same effect as a conduction current, we must in the case, when both conduction current and alteration in the polarisation are present, look upon the true or effective current as the sum of the conduction current and the change in the polarisation.

The components f, g, h of the dielectric polarisation are defined by the equation

$$f = \frac{K}{4\pi}X \qquad g = \frac{K}{4\pi}Y \qquad h = \frac{K}{4\pi}Z,$$

where K is the specific inductive capacity of the medium, X, Y, Z the components of the electromotive force. If u, v, w are the components of the effective current, p, q, r the components of the conduction

current, then Maxwell in his paper on a 'Dynamical Theory of the Electromagnetic Field,' 'Phil. Trans., 1885,' puts

$$u = p + \frac{df}{dt}, \qquad v = q + \frac{dg}{dt}, \qquad w = r + \frac{dh}{dt}.$$

Since
$$\frac{dp}{dx} + \frac{dq}{dy} + \frac{dr}{dz} = -\frac{d\rho}{dt}$$

and
$$\frac{df}{dx} + \frac{dg}{dy} + \frac{dh}{dz} = \rho,$$

where ρ is the volume density of the free electricity, we see that

$$\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} = 0.$$

If the values of the quantities in a medium A be denoting by putting the suffix 1 to the symbols representing them, and those in another dielectric B by putting the suffix 2, then if l, m, n are the direction cosines of the normal from A to B, we have at the boundary of the two media

$$l\,(p_1 - p_2) + m\,(q_1 - q_2) + n\,(r_1 - r_2) = \frac{d\sigma}{dt}$$

$$l\,(f_1 - f_2) + m\,(g_1 - g_2) + n\,(h_1 - h_2) = -\sigma,$$

where σ is the surface density of the electricity; thus

$$l\,(u_1 - u_2) + m\,(v_1 - v_2) + n\,(w_1 - w_2) = 0;$$

so that u, v, w satisfy the same equations as the components of the velocity of an incompressible fluid.

This assumption about the magnitude of the effects produced by the alteration in the dielectric polarisation makes the mathematics of the theory as simple as possible. If Maxwell had merely assumed that the alteration of the dielectric polarisation produces effects analogous to those produced by ordinary conduction currents, and that the equivalent conduction current was proportional to the rate of alteration of the dielectric polarisation, then these equations would have been

$$u = p + \alpha \frac{dX}{dt},$$

$$v = q + \alpha \frac{dY}{dt},$$

$$w = r + \alpha \frac{dZ}{dt};$$

so that in a homogeneous dielectric

$$\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} = -\frac{d\rho}{dt}\left\{1 - 4\frac{\alpha\pi}{k}\right\},$$

$$l(u_1 - u_2) + m\,(v_1 - v_2) + n\,(w_1 - w_2) = \frac{d\sigma}{dt} + \alpha_1 \frac{dN_1}{dt} - \alpha_2 \frac{dN_2}{dt}$$

where N is the component of the electromotive force normal to the surface.

Maxwell's assumption is that $a = \mathrm{K}/4\pi$, and this makes the equations much simpler; it is, however, important to remember that Maxwell's theory of the dielectric involves the two assumptions—

1st. That alterations in the dielectric polarisation produce effects analogous to those of ordinary conduction currents;

2nd. That the magnitude of the equivalent conducting current $= d\left\{\frac{\mathrm{K}}{4\pi}\mathrm{F}\right\}/dt$, where F is the electromotive force at the point; this is equivalent to saying that all the currents are closed currents, and that there is no discontinuity in them.

Maxwell developes his theory by means of the principle of the Conservation of Energy.

Let us consider an electric field full of currents, whether ordinary conduction currents or polarisation ones. Then this field may be looked upon as a material system, and all the phenomena have to be explained as the effects of the motion of this system; a current must be looked upon as a change in the structure of the system, and so capable of representation by means of the differential coefficients of the co-ordinates fixing the system; we can thus represent the current at each point as the differential coefficient of some generalised co-ordinate fixing the system; the components u, v, w of the current passing through an element dx, dy, dz may be looked upon as the rates of change of some generalised co-ordinates; we may write the energy as

$$\tfrac{1}{2}\iiint \{\mathrm{F}u + \mathrm{G}v + \mathrm{H}w\}\,dx\,dy\,dz,$$

where F, G, H may be looked upon as momenta corresponding to u, v, w. It remains to identify F, G, H with known quantities. Maxwell does this by the aid of Faraday's result, that the electromotive force round a circuit equals the rate of diminution of the number of lines of force passing through it.

Let us consider a single linear circuit in which the current is i, or say dq/dt, then the energy

$$= \tfrac{1}{2}\int \frac{dq}{dt}\left\{\mathrm{F}\frac{dx}{ds} + \mathrm{G}\frac{dy}{ds} + \mathrm{H}\frac{dz}{ds}\right\}ds,$$

where ds is an element of circuit; but by Lagrange's equation the force tending to increase q, *i.e.*, the electromotive force in the circuit,

$$= -\frac{d}{dt}\int\left(\mathrm{F}\frac{dx}{ds} + \mathrm{G}\frac{dy}{ds} + \mathrm{H}\frac{dz}{ds}\right)ds;$$

so that

$$\int\left(\mathrm{F}\frac{dx}{ds} + \mathrm{G}\frac{dy}{ds} + \mathrm{H}\frac{dz}{ds}\right)ds$$

equals the number of lines of force passing through the circuit; but if $d\mathrm{S}$ be an element of surface closing up the circuit, l, m, n the direction cosines of the normal, then by Stokes' theorem

$$\int\left(\mathrm{F}\frac{dx}{ds} + \mathrm{G}\frac{dy}{ds} + \mathrm{H}\frac{dz}{ds}\right)ds$$

$$\iint\left\{l\left(\frac{d\mathrm{H}}{dy} - \frac{d\mathrm{G}}{dz}\right) + m\left(\frac{d\mathrm{F}}{dz} - \frac{d\mathrm{H}}{dx}\right) + n\left(\frac{d\mathrm{G}}{dx} - \frac{d\mathrm{F}}{dy}\right)\right\}d\mathrm{S};$$

but the number of lines of force passing through the circuit

$$=\iint(la+mb+nc)dS,$$

where a, b, c are the components of magnetic induction, so that

$$a=\frac{dH}{dy}-\frac{dG}{dz},$$

$$b=\frac{dF}{dz}-\frac{dH}{dx},$$

$$c=\frac{dG}{dx}-\frac{dF}{dy}.$$

To connect a, b, c with the current, Maxwell makes use of the principle that the line integral of the magnetic force taken round any closed curve equals the current flowing through the curve. This leads to the equations—

$$4\pi u=\frac{d\gamma}{dy}-\frac{d\beta}{dz},$$

$$4\pi v=\frac{d\alpha}{dz}-\frac{d\gamma}{dx},$$

$$4\pi w=\frac{d\beta}{dx}-\frac{d\alpha}{dy};$$

so that if μ be the coefficient of magnetic permeability,

$$4\pi\mu u=\frac{dc}{dy}-\frac{db}{dz},$$

and so on. Substituting the values of a, b, c, given above, we find

$$4\pi\mu u=\frac{d}{dx}\left\{\frac{dF}{dx}+\frac{dG}{dy}+\frac{dH}{dz}\right\}-\nabla^2F,$$

with similar equations for G and H.

Now v. Helmholtz, in his paper 'Ueber die Bewegungsgleichungen der Elektricität für ruhende leitende Körper' (Crelle, lxxii. p. 57; *Gesammelte Werke*, ii. p. 545), has investigated the most general expressions for F, G, H, consistent with the force between two closed circuits agreeing with that indicated by Ampère's theory, and he finds that if the circuits are closed circuits, as Maxwell assumes all circuits to be, then

$$\frac{dF}{dx}+\frac{dG}{dy}+\frac{dH}{dz}=0,$$

and therefore $$4\pi\mu u=-\nabla^2F,$$

with similar equations for G and H. These equations are sufficient to determine the quantities F, G, H.

Maxwell does not at once put $dF/dx+dG/dy+dH/dz=0$; he writes J for this quantity, and puts

$$\chi=\iiint\frac{J}{r}dx\,dy\,dz.$$

Then $$F=\iiint\frac{\mu u}{r}dx\,dy\,dz+\frac{d\chi}{dx};$$

as, however, he subsequently puts $J=0$, we may at once simplify the equation by making this assumption.

Since the kinetic energy equals

$$\tfrac{1}{2}\iiint(Fu+Gv+Hw)\,dx\,dy\,dz,$$

we see by Lagrange's equations that the electromotive force tending to increase u

$$=-\frac{dF}{dt};$$

in addition to this there is the force arising from the electrostatic potential ϕ, so that the total electromotive force parallel to the axis of x

$$=-\frac{dF}{dt}-\frac{d\phi}{dx},$$

so that if σ be the specific resistance of the substance, K its specific inductive capacity, then

$$\sigma p=\frac{4\pi}{K}f=-\frac{dF}{dt}-\frac{d\phi}{dx};$$

but
$$u=p+\frac{df}{dt}=-\frac{1}{\sigma}\left\{\frac{dF}{dt}+\frac{d\phi}{dx}\right\}-\frac{K}{4\pi}\left\{\frac{d^2F}{dt^2}+\frac{d^2\phi}{dx\,dt}\right\};$$

but we saw before that

$$4\pi\mu u=-\nabla^2F;$$

substituting for u this value, we see

$$\nabla^2F=\frac{4\pi\mu}{\sigma}\left\{\frac{dF}{dt}+\frac{d\phi}{dx}\right\}+K\mu\left\{\frac{d^2F}{dt^2}+\frac{d^2\phi}{dx\,dt}\right\},$$

thus in the dielectric the equation becomes

$$\nabla^2F=K\mu\left\{\frac{d^2F}{dt^2}+\frac{d^2\phi}{dx\,dt}\right\},$$

in the conductor

$$\nabla^2F=\frac{4\pi\mu}{\sigma}\left\{\frac{dF}{dt}+\frac{d\phi}{dx}\right\}.$$

The equation for the dielectric shows that it represents a wave-motion propagated with the velocity $1/\sqrt{K\mu}$; the numerical value of this velocity agrees very approximately with the velocity of light, and this led Maxwell to the theory that the changes in the structure of the dielectric which take place when the dielectric is polarised are of the same nature as those which constitute light. This theory, which is called the electromagnetic theory of light, might almost as justly be called the mechanical theory of dielectric polarisation. Kirchhoff, in his paper 'Ueber die Bewegung der Electricität in Drähten' (Pogg. *Ann.*, vol. c. 1857; *Gesammelte Werke*, p. 131), was the first to point out that some electrical actions are propagated with the velocity of light. In this paper he considers the motion of electricity in wires whose diameters are small compared with their length. There are three things which have to be considered in this problem—(1) the self-induction of the electric current, and

if the medium be taken into account, that of the polarisation currents in the dielectric. This self-induction produces very much the same effect as if the electric current possessed momentum—(2) the electrostatic action of the free electricity which tends to bring things to a definite state, and corresponds very much to the spring in a material system. Then, lastly, there is the electrical resistance, which corresponds to friction in an ordinary system. We see from the analogy that if the resistance be small enough, the electrical system will vibrate; if, however, the resistance is large, the electrical disturbance will be propagated in the same way as heat. Kirchhoff in his paper considers the propagation of electrical disturbance along a wire under various conditions: we shall only consider here one of these cases; that of an endless wire. In his solution Kirchhoff only considers the self-induction of the current flowing along the wire; he does not consider the effects in the surrounding dielectric. He shows that if e be the quantity of electricity per unit length of the wire, and

$$e = \mathrm{X} \sin ns,$$

where s is the length of a portion of the wire measured from some fixed point, then X satisfies the differential equation

$$\frac{d^2\mathrm{X}}{dt^2} + \frac{c^2 r}{16\gamma l}\frac{d\mathrm{X}}{dt} = \frac{c^2}{2}\frac{d^2\mathrm{X}}{ds^2},$$

where c is a quantity which occurs in Weber's theory, and is the velocity with which two charged particles must move if the electrodynamic attraction between them balances the electrostatic repulsion;

r is the resistance of the wire in electrostatic measure; $\gamma = log\ l/a$,

where l is the length of the wire and a the radius of its cross section. The form of the solution of this equation depends on the magnitude of

$$\frac{32\gamma}{cr\sqrt{2}} nl.$$

If this quantity be large, the solution takes the form representing the propagation of a wave along the wire with the velocity $c/\sqrt{2}$. Weber's researches show that this velocity is very nearly equal to the velocity of light. If, however, the above-mentioned quantity be small, then the solution of the equation takes the same form as the formula which expresses the conduction of heat along the wire. We must not, however, take this to mean that the electric disturbance is propagated with an infinite velocity, so that if we had an infinitely delicate electrometer at a finite distance from the source of disturbance we could detect an electrification after an indefinitely short time, for it seems obvious that the electrical resistance cannot increase the velocity of propagation any more than the resistance of the air could increase the velocity of propagation of a disturbance along a line of particles connected by an elastic string. The conditions at the end help to determine the form of the solution, and these cannot make themselves felt until the disturbance has reached it; thus the heat form of solution probably only holds after a time from the commencement of the disturbance greater than the time taken by light to travel along the wire. If we take the case of a copper wire one square centimetre in area, we shall find that the wave form of solution will hold if the wire is not more than 100 miles in length, while the heat form will correspond to wires which are much longer than this. Kirchhoff's

solution only refers to the propagation of a disturbance in a conductor, while Maxwell's refers to the propagation of such a disturbance in the dielectric.

Maxwell considers the effect of the motion of the medium on the electromotive force; he shows that the electromotive force parallel to the axis of x

$$= cv - bw - \frac{dF}{dt} - \frac{d\psi}{dx},$$

where u, v, w are the components of the velocity of the medium conveying electric action. Here ψ is not the electrostatic potential merely; it is equal, as Helmholtz has shown,[1] to the electrostatic potential plus the term

$$Fu + Gv + Hw.$$

We must remark here that u, v, w are the components of the velocity of the medium conveying the electric action, *i.e.* the ether, and this need not necessarily be the same as the velocity of the dielectric.

v. Helmholtz's Dielectric Theory.

v. Helmholtz, in the paper[2] to which we have so often referred, considers the effect of the polarisation of the dielectric; he supposes that when an electromotive force X, parallel to the axis of x, acts on an element of a dielectric, it puts it into such a state that it produces the same effect as if there were electricity of surface-density $\mathfrak{x}$ on the face $dy\,dz$ of the element, and an equal quantity of electricity of the opposite sign on the parallel face, $\mathfrak{x}$ being given by the equation

$$\mathfrak{x} = \epsilon X,$$

the variations in the electromotive forces acting on the dielectric are supposed to produce the same effect as ordinary conduction currents whose components are $\dot{\mathfrak{x}}, \dot{\mathfrak{y}}, \dot{\mathfrak{z}}$, where $\mathfrak{x}, \mathfrak{y}, \mathfrak{z}$ are the components of a vector quantity which in isotropic media is parallel to the electromotive force and equal to the product of ϵ and the intensity of the force. This agrees with Maxwell's assumption, provided

$$\epsilon = K/4\pi,$$

where K is the specific inductive capacity of the dielectric. If ϕ be the electrostatic potential of the free electricity, ψ the potential due to the polarisation of the dielectric, then Helmholtz shows that

$$\frac{d}{dx}\left\{(1+4\pi\epsilon)\frac{d}{dx}(\phi+\psi)\right\} + \frac{d}{dy}\left\{(1+4\pi\epsilon)\frac{d}{dy}(\phi+\psi)\right\}$$
$$+\frac{d}{dz}\left\{(1+4\pi\epsilon)\frac{d}{dz}(\phi+\psi)\right\} = -4\pi E,$$

where E is the volume-density of the free electricity. The corresponding equation in Maxwell's theory is of the same form, provided

$$1 + 4\pi\epsilon = K.$$

[1] *Ueber die Theorie der Elektrodynamik; die elektrodynamische Kräfte in bewegten Leitern,* Crelle, lxxviii. p. 309; *Gesammelte Werke,* ii. p. 745.

[2] *Ueber die Theorie der Elektrodynamik,* Crelle, lxxii. p. 57; *Gesammelte Werke,* i. p. 544.

This relation seems inconsistent with the previous one; it may, however, be reconciled with it in the following way:—

The potential due to a quantity E of electricity at a point distant r from it is proportional to

$$\frac{E}{(1+4\pi\varepsilon)r}.$$

If ε_0 be the value of ε for air, the potential under the same circumstances in air is proportional to

$$\frac{E}{(1+4\pi\varepsilon_0)r};$$

if, then, we define unit potential as the potential at unit distance from unit of electricity in air, the potential due to a quantity E in another medium will be

$$\left\{\frac{1+4\pi\varepsilon_0}{1+4\pi\varepsilon}\right\}\frac{E}{r}.$$

We see that this is equivalent to increasing the unit of potential, and therefore the unit electromotive force, $1+4\pi\varepsilon_0$ times, so that if we use the new unit the equations will be

$$\mathfrak{x}=\frac{\varepsilon}{1+4\pi\varepsilon_0}X,$$

$$\frac{d}{dx}\left\{\frac{1+4\pi\varepsilon}{1+4\pi\varepsilon_0}\frac{d}{dx}(\phi+\psi)\right\}+\dots\quad=-4\pi E.$$

These will coincide with Maxwell's equation if we make ε and ε_0 each infinite and put $K=\varepsilon/\varepsilon_0$.

Returning to Helmholtz's theory, if u, v, w are the components of the total current

$$u=p+\dot{\mathfrak{x}},$$
$$v=q+\dot{\mathfrak{y}},$$
$$w=r+\dot{\mathfrak{z}},$$

where p, q, r are the components of the conduction current.

Helmholtz puts

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=-\frac{d\rho}{dt},$$

where ρ is the volume-density of the free electricity, and if σ be the surface-density of the free electricity at any point of a surface separating two media, u_1, v_1, w_1; u_2, v_2, w_2 the components of the current in the two media, l, m, n the direction cosines of the normal to the surface drawn from the first medium to the second, then according to v. Helmholtz

$$l\,(u_1-u_2)+m\,(v_1-v_2)+n\,(w_1-w_2)=\frac{d\sigma}{dt}.$$

According to Maxwell the corresponding equations are

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=0,$$

$$l\,(u_1-u_2)+m\,(v_1-v_2)+n\,(w_1-w_2)=0.$$

As it is in the difference between these equations that the difference in the theory really lies, it will be instructive to look at them from another point of view. We know of no way in which the quantity of free electricity can be altered except by electricity being conveyed by conduction currents to the place where the alteration takes place. Assuming, then, that the alteration in the density is caused by such currents

$$\frac{dp}{dx}+\frac{dq}{dy}+\frac{dr}{dz}=-\frac{d\rho}{dt},$$

$$l\,(p_1-p_2)+m\,(q_1-q_2)+n\,(r_1-r_2)=\frac{d\sigma}{dt}.$$

So that Helmholtz's equations taken in conjunction with these are equivalent to the condition

$$\frac{d\dot{\mathfrak{x}}}{dx}+\frac{d\dot{\mathfrak{y}}}{dy}+\frac{d\dot{\mathfrak{z}}}{dz}=0\,;$$

$$l\,(\dot{\mathfrak{x}}_1-\dot{\mathfrak{x}}_2)+m\,(\dot{\mathfrak{y}}_1-\dot{\mathfrak{y}}_2)+n\,(\dot{\mathfrak{z}}_1-\dot{\mathfrak{z}}_2)=0.$$

Thus on Helmholtz's theory the dielectric currents behave like the flow of an incompressible fluid, while on Maxwell's theory it is the total current, which is the sum of the conduction currents and the dielectric currents which behave in this way.

The equations we have arrived at for the dielectric currents seem inconsistent with Helmholtz's definition of them; for since

$$\mathfrak{x}=\epsilon X,$$

with similar equations for $\mathfrak{y}$ and $\mathfrak{z}$, and since in a medium at rest

$$X=-\frac{dU}{dt}-\frac{d\phi}{dx},$$

$$Y=-\frac{dV}{dt}-\frac{d\phi}{dy},$$

$$Z=-\frac{dW}{dt}-\frac{d\phi}{dz},$$

where U, V, W are the components of the vector potential. If we consider a surface separating two portions of the same dielectric and coated with electricity whose surface-density is σ, we have, since U, V, W are not discontinuous on crossing the surface,

$$l\,\{\dot{\mathfrak{x}}_1-\dot{\mathfrak{x}}_2\}+m\,(\dot{\mathfrak{y}}_1-\dot{\mathfrak{y}}_2)+n\,(\dot{\mathfrak{z}}_1-\dot{\mathfrak{z}}_2)=-\epsilon\,\frac{d}{dt}\left[l\,\frac{d\phi}{dx}+m\,\frac{d\phi}{dy}+n\,\frac{d\phi}{dz}\right]_1^2,$$

where $\left[l\,\frac{d\phi}{dx}+m\,\frac{d\phi}{dy}+n\,\frac{d\phi}{dz}\right]_1^2$ denotes the difference between the values of $l\,\frac{d\phi}{dx}+m\,\frac{d\phi}{dy}+n\,\frac{d\phi}{dz}$ on the two sides of the surface.

But
$$\left[l\,\frac{d\phi}{dx}+m\,\frac{d\phi}{dy}+n\,\frac{d\phi}{dz}\right]_1^2=-\frac{1}{1+4\pi\epsilon}\,\sigma,$$

so that
$$l\,(\dot{\mathfrak{x}}_1-\dot{\mathfrak{x}}_2)+m\,(\dot{\mathfrak{y}}_1-\dot{\mathfrak{y}}_2)+n\,(\dot{\mathfrak{z}}_1-\dot{\mathfrak{z}}_2)=\frac{\epsilon}{1+4\pi\epsilon}\,\frac{d\sigma}{dt},$$

and so cannot vanish if the surface-density of the electricity changes;

thus Helmholtz's equation seems to be inconsistent with the principle that the change in the quantity of free electricity is caused by conduction currents. In the case above considered, Maxwell's equations lead to no difficulty; it does not follow, however, that Maxwell's assumption that the total current behaves like the flow of an incompressible fluid is absolutely necessary. We shall consider later on the differences which the abandonment of this assumption will make in the theory.

We shall now go on to consider Helmholtz's equations and compare them with the corresponding ones in Maxwell's theory.

The quantities U, V, W are given by equation of the form

$$\mathrm{U}=\tfrac{1}{2}(1-k)\frac{d\psi}{dx}+\iiint\frac{u}{r}d\xi\,d\eta\,d\zeta,$$

where k is the constant which we mentioned before as occurring in Helmholtz's theory, and

$$\psi=-\frac{1}{2\pi}\iiint\frac{d\phi}{dt}\frac{1}{r}\,d\xi\,d\eta\,d\zeta,$$

where ϕ is the electrostatic potential; it follows from these equations that

$$\frac{d\mathrm{U}}{dx}+\frac{d\mathrm{V}}{dy}+\frac{d\mathrm{W}}{dz}=-k\frac{d\phi}{dt}.$$

The corresponding equation in Maxwell's theory is

$$\frac{d\mathrm{U}}{dx}+\frac{d\mathrm{V}}{dy}+\frac{d\mathrm{W}}{dz}=0,$$

so that these equations coincide if $k=0$. We can see from the value of χ given on page 116 that, on Helmholtz's theory, this quantity would also vanish, whatever be the value of k, if the *total* current behaved like the flow of an incompressible fluid.

If α, β, γ are the components of the magnetic force, then on Helmholtz's theory

$$\frac{d\gamma}{dy}-\frac{d\beta}{dz}=\mathrm{A}\left\{\frac{d^2\phi}{dt\,dx}-4\pi u\right\},$$

$$\frac{d\alpha}{dz}-\frac{d\gamma}{dx}=\mathrm{A}\left\{\frac{d^2\phi}{dt\,dy}-4\pi v\right\},$$

$$\frac{d\beta}{dx}-\frac{d\alpha}{dy}=\mathrm{A}\left\{\frac{d^2\phi}{dt\,dz}-4\pi w\right\},$$

where A is a quantity depending on the unit of current adopted, and is such that the force between two parallel elements of currents at right angles to the line joining them is

$$\tfrac{1}{2}\frac{\mathrm{A}^2}{r^2}i\,j\,ds\,ds',$$

where r is the distance between the elements, $i\,j$ the current through them, and $ds\ ds'$ their lengths; the corresponding equations on Maxwell's theory are

$$\frac{d\gamma}{dy}-\frac{d\beta}{dz}=4\pi u,$$

with similar equations for v and w.

If λ, μ, ν are the intensities of magnetisation, ϑ the coefficient of induced magnetisation, the equations satisfied by the components of the dielectric and magnetic polarisation are of the type

$$\nabla^2\mathfrak{x}=\frac{4\pi\epsilon\,(1+4\pi\vartheta)}{(1+4\pi\epsilon_0)\,(1+4\pi\vartheta_0)}A^2\frac{d^2\mathfrak{x}}{dt^2}+\left\{1-\frac{(1+4\pi\vartheta)\,(1+4\pi\epsilon)}{k}\right\}\frac{d}{dx}\left\{\frac{d\mathfrak{x}}{dx}+\frac{d\mathfrak{y}}{dy}+\frac{d\mathfrak{z}}{dz}\right\},$$

$$\nabla^2\lambda=\frac{4\pi\epsilon\,(1+4\pi\vartheta)}{(1+4\pi\epsilon_0)\,(1+4\pi\vartheta_0)}A^2\frac{d^2\lambda}{dt^2},$$

where ϵ_0 and ϑ_0 are the values of ϵ and ϑ for air.

These equations show that the dielectric and magnetic polarisations are propagated by waves. For the dielectric polarisation longitudinal waves are propagated with the velocity

$$\frac{1}{A}\left\{\frac{(1+4\pi\epsilon)\,(1+4\pi\epsilon_0)\,(1+4\pi\vartheta_0)}{4\pi\epsilon k}\right\}^{\frac{1}{2}}.$$

Transverse waves are propagated with the velocity

$$\frac{1}{A}\sqrt{\frac{(1+4\pi\epsilon_0)\,(1+4\pi\vartheta_0)}{4\pi\epsilon\,(1+4\pi\vartheta)}}.$$

Longitudinal waves of magnetic disturbances are propagated with an infinite velocity, and traverse ones with the same velocity as the transverse waves of dielectric polarisation. The electrostatic potential is propagated with the velocity $1/A\sqrt{k}$. In Maxwell's theory the corresponding equations are

$$\nabla^2 x=\mu K\frac{d^2x}{dt^2},$$

$$\nabla^2\lambda=\mu K\frac{d^2\lambda}{dt^2},$$

where μ is the magnetic permeability and K the specific inductive capacity, so that for both dielectric and magnetic polarisation the velocity of the longitudinal wave is infinite, while the velocity of the transverse wave is $1/\sqrt{\mu K}$. The velocity of propagation of the electrostatic potential is infinite. If in Helmholtz's theory we put $k=0$, $\vartheta_0=0$, $\epsilon/\epsilon_0=K$, while both ϵ and ϵ_0 are infinite, we see that the results of his theory will in this respect agree with Maxwell's.

Though in Maxwell's theory the velocity of propagation of the electrostatic potential is infinite, and in Helmholtz's theory $1/A\sqrt{k}$, the electromotive force at a point, and consequently the dielectric polarisation, does not travel with an infinite velocity in Maxwell's theory, or with the velocity $1/A\sqrt{k}$ in Helmholtz's. We can see the reason of this more easily from Maxwell's theory, as the equations are simpler.

Using the notation of that theory, viz., f, g, h, for the components of the electric displacement, F, G, H for the components of the vector potential, and ϕ for the electrostatic potential, then in a dielectric the equations are

$$\frac{4\pi}{K}f=-\frac{dF}{dt}-\frac{d\phi}{dx}$$

$$\frac{4\pi}{K}\frac{df}{dt} = -\frac{d^2F}{dt^2} - \frac{d^2\phi}{dx\,dt};$$

but, since

$$4\pi\mu\frac{df}{dt} = -\nabla^2 F,$$

we see that

$$\frac{1}{\mu K}\nabla^2 F = \frac{d^2F}{dt^2} + \frac{d^2\phi}{dx\,dt}.$$

Now, since $\nabla^2\phi = 0$, a particular solution of this differential equation will be

$$\frac{dF}{dt} + \frac{d\phi}{dx} = 0,$$

while the general solution will be the sum of this solution and the general solution of

$$\frac{1}{\mu K}\nabla^2 F = \frac{d^2F}{dt^2}.$$

The particular solution is propagated at the same rate as ϕ, while the other part of the solution represents a wave travelling with the velocity $1/\sqrt{\mu K}$. Since the part of the solution which travels at an infinite rate satisfies the equation

$$\frac{dF}{dt} + \frac{d\phi}{dx} = 0$$

or

$$f = 0,$$

we see that the electromotive force due to the change in the vector potential just balances the electrostatic electromotive force, so that until the part of the vector potential which travels at the rate $1/\sqrt{\mu K}$ comes up the resultant electromotive force vanishes. This explains how the electromotive force on Maxwell's theory travels at a different rate from the potential, and a similar explanation will apply to Helmholtz's theory. Helmholtz's equations for a conductor are

$$\sigma\nabla^2 u = (1+4\pi\vartheta)\,4\pi A^2\frac{du}{dt} - \frac{d}{dx}\left\{\nabla^2\phi + (1+4\pi\vartheta-k)\,A^2\frac{d^2\phi}{dt^2}\right\}$$

where σ is the specific resistance of the conductor; on Maxwell's theory the equations are

$$\sigma\nabla^2 u = 4\pi\mu\frac{du}{dt},$$

These equations differ by terms involving the unknown constant k; but v. Helmholtz's[1] investigations on the motion of electricity along thin conducting wires show that there is not much hope of distinguishing between the theories by experiments on conductors. We have seen that we can make certain equations which occur in Helmholtz's theory coincide with the corresponding ones in Maxwell's by giving particular values to certain constants. The difference in Helmholtz's and Maxwell's views as to the continuity of the currents is too serious to let us expect that we should ever get a complete agreement between the

[1] *Ueber die Bewegungsgleichungen der Elektricität für ruhende leitende Körper. Gesammelte Werke*, vol. i. p. 603.

theories; and, in fact, make as many assumptions about the constants as we may, there are still differences between the theories.

In order to get as general a theory of these dielectric currents as possible, we shall investigate the consequences of assuming merely that these currents are proportional to the rate of change of the electromotive force, and write dielectric current$=\eta$ (rate of change of the electromotive force), where η is a constant which for the present is left indeterminate; In Maxwell's theory $\eta=\mathrm{K}/4\pi$, where K is the specific inductive capacity of the dielectric; in Helmholtz's theory, η is also proportional to the specific inductive capacity. We shall denote the components of the dielectric currents by the symbols $\dot{f}, \dot{g}, \dot{h}$; the components of the conduction current by p, q, r, and the components of the total current by u, v, w, so that

$$u=p+\dot{f}.$$

Let us put

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=\mathrm{P},$$

$$l\,(u_1-u_2)+m\,(v_1-v_2)+n\,(w_1-w_2)=\Sigma\,;$$

on Maxwell's theory P and Σ are each zero.

If F, G, H are the components of the vector potential, then by v. Helmholtz's investigation of the most general expression possible for these quantities consistent with the condition that the forces between closed circuits should agree with those given by Ampère's laws,

$$\mathrm{F}=\tfrac{1}{2}\,(1-k)\,\frac{d\psi}{dx}+\mu\iiint\frac{u}{r}\,d\xi\,d\eta\,d\zeta,$$

with similar expressions for G and H, where k is a constant and

$$\psi=\iiint\mu\left(u\,\frac{dr}{d\xi}+v\,\frac{dr}{d\eta}+w\,\frac{dr}{d\zeta}\right)d\xi\,d\eta\,d\zeta.$$

Transforming this expression we see, using the same notation as before, that

$$\begin{aligned}\psi=&\iint r\mu\,\{l\,(u_1-u_2)+m\,(v_1-v_2)+n\,(w_1-w_2)\}\,d\mathrm{S}\\&\qquad-\iiint r\mu\left(\frac{du}{d\xi}+\frac{dv}{d\eta}+\frac{dw}{d\zeta}\right)d\xi\,d\eta\,d\zeta\\=&\iint\mu r\,\Sigma\,d\,\mathrm{S}-\iiint\mu r\,\mathrm{P}\,d\xi\,d\eta\,d\zeta,\end{aligned}$$

where $d\mathrm{S}$ is an element of a surface at which there is discontinuity in u, v, w.

Let us now consider the equations which hold in a perfectly insulating dielectric.

The rate of change of the x component of the electromotive force in a medium at rest

$$=-\frac{d^2\mathrm{F}}{dt^2}-\frac{d^2\phi}{dt\,dx},$$

where ϕ is the electrostatic potential; it also equals $\dot{f}/\eta$, so that

$$\frac{\dot{f}}{\eta}=-\frac{d^2\mathrm{F}}{dt^2}-\frac{d^2\phi}{dt\,dx}.$$

Since in this case there is no conduction current $u = \dot{f}$, and the preceding equation for F shows that

$$\nabla^2 F = \tfrac{1}{2}(1-k)\frac{d}{dx}\nabla^2\psi - 4\pi\mu\dot{f}.$$

substituting for $\dot{f}$

$$\nabla^2 F - \tfrac{1}{2}(1-k)\frac{d}{dx}\nabla^2\psi = 4\pi\eta\left\{\frac{d^2F}{dt^2} + \frac{d^2\phi}{dx\,dt}\right\}.$$

if $\dfrac{dF}{dx} + \dfrac{dG}{dy} + \dfrac{dH}{dz} = \chi$, we get, by differentiating this expression, with regard to x and the corresponding equations for G and H with regard to y and z respectively, and adding

$$\nabla^2\chi - \tfrac{1}{2}(1-k)\,\nabla^4\psi = 4\pi\eta\mu\left\{\frac{d^2}{dt^2}\chi + \frac{d}{dt}\nabla^2\phi\right\}.$$

Now, as the dielectric is a perfect insulator, there are no conduction currents, so that the density of the free electricity remains constant, and therefore

$$\frac{d}{dt}\nabla^2\phi = 0.$$

From the expression for ψ we see that

$$\begin{aligned}\nabla^4\psi &= +\,8\pi P \\ &= -\,8\pi\eta\mu\left(\frac{d^2\chi}{dt^2} + \frac{d}{dt}\nabla^2\phi\right) \\ &= -\,8\pi\eta\mu\frac{d^2\chi}{dt^2}.\end{aligned}$$

Substituting this value of $\nabla^4\psi$ in the equation for χ, we get

$$\nabla^2\chi = 4\pi\eta\mu k\frac{d^2\chi}{dt^2},$$

which represents the propagation of a normal wave with the velocity

$$1/\sqrt{4\pi\eta k}.$$

The transverse wave is propagated with the velocity $1/\sqrt{4\pi\eta\mu}$, so that if the view that light consists of electric or magnetic disturbances be correct, since experiment shows that this velocity is very nearly equal to $1/\sqrt{K\mu}$, we must have $4\pi\eta = K$ or $\eta = K/4\pi$, which is Maxwell's theory. So that if we assume that light is an electric phenomenon, then in those media in which its velocity $= 1/\sqrt{\mu K}$ Maxwell's theory that the electric currents flow like an incompressible fluid must be true.

If α, β, γ are the components of the magnetic force, then, since

$$F = \tfrac{1}{2}(1-k)\frac{d\psi}{dx} + \mu\iiint\frac{u}{r}\,d\xi\,d\eta\,d\zeta,$$

we see from Ampère's formula for the magnetic force due to a circuit that

$$\mu\alpha = \frac{dH}{dy} - \frac{dG}{dz} - \mu\frac{dV}{dx},$$

where V is the magnetic potential due to the magnetism in the field both permanent and induced. From these equations we get

$$\mu\left\{\frac{d\alpha}{dy}-\frac{d\beta}{dx}\right\}=\nabla^2 H-\frac{d}{dz}\left(\frac{dF}{dx}+\frac{dG}{dy}+\frac{dH}{dz}\right)$$

$$=-4\pi\mu w+\frac{d}{dz}\left\{\tfrac{1}{2}(1-k)\nabla^2\psi-\chi\right\}$$

instead of the equation

$$\frac{d\alpha}{dy}-\frac{d\beta}{dx}=-4\pi w.$$

We have been obliged to introduce another assumption here, viz., that the magnetic force due to an element of current is given by Ampère's expression.

We could not assume Maxwell's way of connecting currents with magnetic force, viz. that the total current flowing through any closed curve is equal to the line integral of the magnetic force round the curve, for the result can only be true when the currents flow like an incompressible fluid.

Let us now go on to consider the force acting on the medium conveying the current.

If we consider a continuous distribution of currents, the kinetic energy

$$=\tfrac{1}{2}\iiint (Fu+Gv+Hw)\,dx\,dy\,dz.$$

If we derive the force parallel to x by the variation of the energy in the usual way we find, just as in Helmholtz's paper,[1] that the force parallel to x

$$=\left\{v\left(\frac{dG}{dx}-\frac{dU}{dy}\right)+w\left(\frac{dH}{dx}-\frac{dU}{dz}\right)-F\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)\right\},$$

or with our notation

$$=v\left\{\frac{dG}{dx}-\frac{dU}{dy}\right\}+w\left\{\frac{dH}{dx}-\frac{dU}{dz}\right\}-FP,$$

and that on any surface where there is a discontinuity in the values of u, v, w there is a force equal per unit of area to

$$F\{l(u_1-u_2)+m(v_1-v_2)+n(w_1-w_2)\}$$

or $F\Sigma$.

In the same paper it is shown that it follows from the principle of the Conservation of Energy that the force exerted by a distribution of currents equals the force given by Ampère's expression along with a force at the point $\xi\eta\zeta$ whose component parallel to the axis of x equals

$$\iiint\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)\frac{x-\xi}{r^4}\Big(u'(x-\xi)+v'(y-\eta)+w'(z-\zeta)\Big)dx\,dy\,dz$$

$$+\iint\left\{l(u_1-u_2)+m(v_1-v_2)+n(w_1-w_2)\right\}\frac{x-\xi}{r^2}\Big(u'(x-\xi)$$

$$+v'(y-\eta)+w'(z-\zeta)\Big)dS;$$

[1] *Die elektrodynamischen Kräfte in bewegten Leitern*, Crelle, lxxviii. p. 298. 1874, or *Gesammelte Werke*, vol. i. p. 733.

or with our notation

$$\iiint \mathrm{P}\,\frac{x-\xi}{r^4}\Big(u'\,(x-\xi)+v'\,(y-\eta)+w'\,(z-\zeta)\Big)\,dx\,dy\,dz$$

$$+\iint \Sigma\,\frac{x-\xi}{r^4}\Big(u'\,(x-\xi)+v'\,(y-\eta)+w'\,(z-\zeta)\Big)\,d\mathrm{S},$$

where u', v', w' are the components of the current at the point $\xi\,\eta\,\zeta$; so that in addition to Ampère's forces we have additional forces wherever P and Σ have finite values. From the above expressions we see that any element where P has a finite value exerts a repulsive force equal per unit of volume to

$$\frac{\mathrm{P}}{r}\,i\cos\theta,$$

tending from the element; where r is the distance of the element from the point at which the force is reckoned, i the intensity of the current at this point, and θ the angle between the direction of the current and r. Any element of surface where Σ has a finite value exerts a repulsive force equal per unit of surface to

$$\frac{\Sigma}{r}\,i\cos\theta,$$

where the notation is the same as before. Of course none of these forces exist in Maxwell's theory. They could be most easily detected in cases where the part of the forces given by Ampère's theory vanishes as it would for the case of an endless solenoid. In this case, though the Ampèrian forces vanish, the forces due to the discontinuity in the current do not, so that if the endless solenoid were to move under the action of external currents it would denote the existence of discontinuity in the current. An experiment of this kind has been made by Schiller; we shall discuss the results of it later.

To sum up, the differences between the most general theory which takes into account the action of the dielectric, and Maxwell's, are—

1. The existence of a normal wave in the general theory, but not in Maxwell's.

2. The difference in the velocity of propagation of the transverse wave.

3. The difference in the relation between electric currents and magnetic force.

4. The forces which arise from discontinuity in the currents.

The Experimental Evidence as to the Truth of the various Theories.

The theories we have considered may be divided into two great classes, according as they do or do not take into account the action of the dielectric surrounding the various conductors in the field. The first thing, therefore, that we have to do is to see whether experiment throws any light on this point.

When a dielectric is in an electric field it experiences a change in its structure; this is rendered evident by the alterations in its volume and elasticity observed by Quincke, by the change in its optical properties

observed by Kerr, and also by the fracture of the dielectric when the field is made sufficiently intense. So that whenever an electromotive force acts on a dielectric it produces a change in its structure which we shall always speak of as polarisation. This, strictly speaking, has only been directly proved for electromotive forces produced by charges of statical electricity; but, unless we are prepared to say that the electromotive force due to statical electricity is in some way different from that due to a changing current, we must admit that when an electromotive force of the latter kind acts on a dielectric it polarises it. And we are not without experimental evidence that the electromotive force due to variations in the vector potential does produce some of the effects of the electromotive force due to a charge of statical electricity. Rowland's experiments have shown that a moving electrified body will set a magnet placed near to it in motion. It follows from this, by dynamical principles, that if we have the charged body initially at rest and move the magnet it will, if no other forces act upon it, be set in motion; so that in this case there is an electromotive force due to the motion of the magnet, *i.e.*, the variation in the vector potential produces the same effect on the electrified body as the electromotive force due to a charge of statical electricity. For this reason we shall suppose that the electromotive force due to the variation in the vector potential always produces effects on a dielectric on which it acts of the same type as those which have been observed to arise from the action of an electromotive force due to a charge of statical electricity.

Let us now consider a magnet surrounded by a dielectric. If we set the magnet in motion, we produce an electromotive force which polarises the dielectric. Let us, to fix our ideas, consider an element of the dielectric and the magnet. When the magnet moves it polarises the dielectric; it follows from dynamical principles (an extension of the principle of action and reaction),[1] that if the polarisation of the dielectric be altered, the magnet will move, so that a change in the polarisation of a dielectric produces a magnetic force.

Again, let us instead of the magnet consider a coil of wire conveying a current. A change in the rate of flow of the current produces a change in the polarisation of the dielectric; it follows that a change in the rate of change of the polarisation of the dielectric will produce a change in the current, *i.e.*, will produce an electromotive force.

It follows too, from dynamical principles, that as the change in the polarisation of an element of the dielectric due to the change in the current depends on the distance of the element from the current, there must be a force between the current and the element when the polarisation of the latter is changing. Thus we see that a change in the polarisation of the dielectric must produce all the effects of an ordinary conduction current, so that it is only absolutely necessary to consider how the experimental evidence affects those theories which take the action of the dielectric into account. As, however, the experiments which have been made are few in number, and are all concerned with interesting points, we shall consider them in their relation to all the theories, and not only to those which take the dielectric into account.

[1] See a paper by the author of this report 'On some Applications of Dynamical Principles to Physical Phenomena,' *Phil. Trans.*, 1885.

Schiller's Experiments.

The first experiment which we shall discuss is one made by Schiller, and described by him in Poggendorf's Annalen, vol. clix. pp. 456, 537; it was intended to test the potential theories of Neumann and Helmholtz. We saw that, according to these theories, in an unclosed circuit there are, in addition to the forces due to the elements of current, and which are expressed by Ampère's law, forces arising from the discontinuity of the currents at the ends of the circuit. If we have an end of a circuit where the current stops, and the electricity accumulates at the rate de/dt, it will exert on an element of current of length ds traversed by a current of intensity i a force tending to the end and equal to

$$A^2 ids \frac{de}{dt} \frac{\cos\theta}{r}$$

where θ is the angle between the element of current and the radius drawn to it from the end. If we calculate from this expression the couple produced by an end on an endless solenoid, or on what is practically the same thing, a ring magnet, we shall find that the couple tending to turn the ring about an axis in its own place will not vanish, while the couple arising from the forces given by Ampère's law will. Thus if the ring rotates, as it should according to the potential theory, it must be from the action of the end.

In Schiller's experiment the end of the current was the end of wire connected with a Holtz machine. This was placed near to a ring magnet which was suspended by a long cocoon fibre; the magnet was protected from electrostatic influences by being enclosed in a metal box connected with the earth. Schiller determined the intensity of magnetisation of the ring magnet and the quantity of electricity passing through the point, and he calculated that if the potential theory were true, he ought to get a deflection of the magnet of about 27 scale divisions, instead of which there was no perceptible deflection.

This experiment shows conclusively that the potential theory is wrong if we neglect altogether the action of the dielectric, and assume the current to stop at the end of the wire. If, however, we take the dielectric into account, the experiment tells us nothing as to whether Maxwell's theory or the more general one is true; for since the current from the Holtz machine is steady, as much electricity flows out from the end of the wires as arrives there; and thus there is really no discontinuity in the current, the only difference being that before reaching the end the current is flowing through copper and after passing it through air. The condition of things at the end of the wire remains steady, and thus the quantities which we denoted by P and Σ vanish.

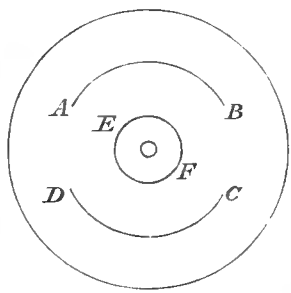
The experiment might, however, be modified so as to be capable of distinguishing between the theories which take the dielectric into account. For suppose that, instead of letting the electricity escape through the point, we never let the potential at the end of the wire get so high as to allow the electricity to escape; then if the wire is initially uncharged, the condition at the end will be changing whilst the wire is charging up, and thus Σ will have a finite value; so that if the magnet were sufficiently delicate and remained undeflected, whilst the point was surrounded by dielectrics of all kinds, it would show that Maxwell's theory is correct.

I have calculated the effect which would be produced on Schiller's

suspended magnet, and find that it is too small to be observed; as, however, the time of charging up the wire will be very small compared with the time of vibration of the magnet, the effect will be of the nature of an impulse, so that in this case there will be considerable advantage in having the moment of inertia of the suspended magnet small; while, as Schiller arranged the experiment, there was no such advantage, as the thing expected was a steady deflection. Thus if the ring magnet were retained it would be desirable to make the opening of it as small as possible, retaining the same cross action. I think the arrangement could be made sensitive enough to be deflected if the value of Σ were any considerable fraction of the rate of increase of the electricity at the end of the wire.

There is another way in which the continuity or discontinuity of the current might be tested, and which might perhaps be more delicate than the last. We saw on p. 141 that at any point of a current at which Σ had a finite value the mechanical force on the element is not at right angles to the element. In addition to the ordinary force at right angles to the element, there is a force in the direction of the vector potential equal in magnitude to the product of the values of the vector potential and Σ.

The existence of this force could be tested by an arrangement of the following kind:—



AB and CD are light movable segments of the same circle, having balls covered with paraffin A, B, C, D fastened to their ends. These segments are connected with a very light framework which can rotate about an axis perpendicular to the plane of the segments; the segments touch at their middle points contact-pieces which are connected with a Holtz machine. EF is the section of an electromagnet concentric with AB and CD; the whole is surrounded with a metal cylinder to screen it from external electric influences. When a current is passing through the electromagnet it produces a vector potential, whose direction is at right angles to the radius from O, the centre of the electromagnet perpendicular to its axis. Thus if Σ exists there will be a couple tending to twist the system AB, CD about its axis, but if Σ exists at all it will be when the electrical condition of the balls A, B, C, D is changing, so that unless the currents are continuous we should expect the system to rotate when the balls are being charged up. I have calculated that the system might easily be made sensitive enough to be sensibly deflected on charging or discharging, provided Σ is an appreciable fraction of the rate of change of the surface-density of the electricity on the balls.

Schiller's Second Experiment.[1]

Schiller has made another experiment, which shows that Ampère's theory fails for unclosed circuits. The first form of the experiment consisted in having a solenoid placed over a condenser one of whose plates could rotate about a vertical axis coinciding with the axis of the solenoid. One end of the solenoid was connected to one plate of the condenser and the other end to the other plate. When the solenoid is connected to a

[1] Pogg. *Ann.*, clix. p. 456; clx. p. 333.

battery the condenser will charge up and there will be radial currents of electricity in the plates; the current passing through the solenoid will produce a magnetic force which will, if Ampère's theory be true, act on the radial currents in the plate of the condenser and set it in rotation. Schiller found that this effect was too small to be observed, so he modified the experiment in the following way. Let us suppose that we have the two plates of the condenser rigidly attached to their axis and placed in a field symmetrical about its axis, in which the vertical component of the magnetic force is not uniform. Then if a current be sent through the upper plate, down through the axis, and out at the lower plate, the couple tending to twist the lower plate will not be equal and opposite to that tending to twist the upper one, as the magnetic force is not equal at the two plates, and thus the condenser will be set in rotation. Conversely, if the condenser be set in rotation in the magnetic field, and two electrodes of a galvanometer be connected with its axis, then if Ampère's theory be true there will be an electromotive force acting round the galvanometer circuit, which will produce a current, and this current could be much more easily detected than the rotation in the first form of the experiment. Schiller calculated the deflection which he ought to get if Ampère's theory were true, and found that he could easily detect it if it existed; as he was not able to see any deflection, we must conclude that Ampère's theory is not the true one.

It is easy to see that, according to the potential theory, there would be no current in the galvanometer; for, as everything is symmetrical about the axis, the potential is not altered by the rotation. The following calculation will show that, according to the dielectric theories, there should be no current through the galvanometer.

For if a, b, c are the components of magnetic induction, F, G, H those of the vector potential, X, Y, Z those of the electromotive force, then

$$\mathrm{X} = c\frac{dy}{dt} - b\frac{dz}{dt} - \frac{d}{dx}\left\{\mathrm{F}\frac{dx}{dt} + \mathrm{G}\frac{dy}{dt} + \mathrm{H}\frac{dz}{dt}\right\},$$

$$\mathrm{Y} = a\frac{dz}{dt} - c\frac{dx}{dt} - \frac{d}{dy}\left\{\mathrm{F}\frac{dx}{dt} + \mathrm{G}\frac{dy}{dt} + \mathrm{H}\frac{dz}{dt}\right\}.$$

Suppose the condenser is rotating with an angular velocity ω about the axis of Z; then the E.M.F. arising from one plate is, if R be its radius,

$$\omega\int_0^{\mathrm{R}} cr\,dr - \left(\mathrm{F}\frac{dx}{dt} + \mathrm{G}\frac{dy}{dt}\right),$$

Now
$$\mathrm{F}\frac{dx}{dt} + \mathrm{G}\frac{dy}{dt} = \omega\mathrm{R}\Theta,$$

where Θ is the component of the vector potential along the direction of motion of a point on the circumference of the plate of the condenser.

But the line integral of the vector potential round any curve equals the number of lines of magnetic force passing through it, so that, since the field is symmetrical,

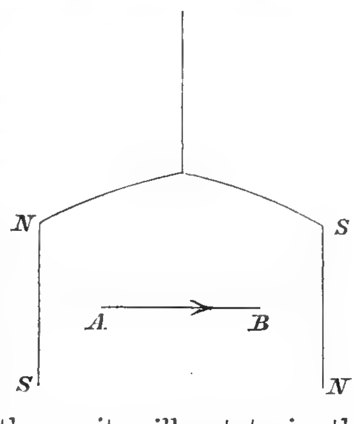
$$2\pi\int_0^{\mathrm{R}} cr\,dr = 2\pi\mathrm{R}\Theta.$$

From this equation we see that the E.M.F. due to the rotation vanishes for each plate, so that, according to this theory, there should be no current through the galvanometer.

This experiment of Schiller shows that both Grassmann's and Clausius' theories must be wrong, as well as Ampère's and Korteweg's, for we can easily see that they would make the disc rotate in the way in which Schiller first tried the experiment, and if this were so, it follows from dynamical principles that a current must be produced in the second form of the experiment.

This would seem to be the case even if we take into account the currents in the dielectric, unless we suppose that all the circuits are closed, for if all the circuits are closed then the disc will not rotate, as all the theories agree. If the circuits are not closed we may divide the currents in the disc into two parts, one part being of such magnitude as to form with the dielectric currents closed circuits; then the forces on this part and the dielectric will form a system in equilibrium; and there remains the other part of the currents, the action of the magnet on which ought to set the disc in rotation. Taking Schiller's experiments together, we may say that they show that the dielectric must be taken into account, and that some form of the potential theory is the only one of the theories we are considering which can give the expression for the forces due to a distribution of currents.

Although these two experiments of Schiller's show that of the theories we have discussed only the dielectric ones can be retained, we shall describe one or two more experiments which have been or could be made to distinguish between the various theories. Clausius' and Grassmann's theories lead to the same expression for the force between two elements of current, so that these theories stand or fall together. Grassmann in his paper[1] describes an experiment which would distinguish between his theory and Ampère's, or, in fact, any other except Clausius' which has ever been published.

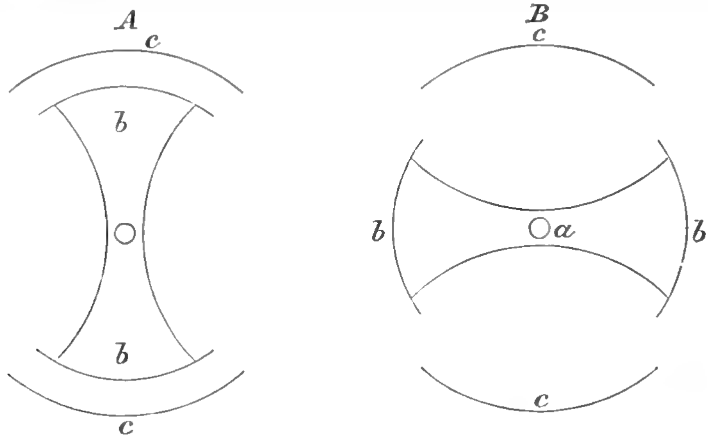


Suppose that NS and SN are two magnets whose north and south poles are denoted by N and S respectively, and that these magnets are fastened together by a rod NS, the system being suspended by a cocoon thread attached to the middle point of NS. Let AB be an unclosed circuit, say a wire joining the plates of a charged condenser; then, according to Grassmann's and Clausius' theories, the system will rotate in such a way that the sense of rotation is related to a vertical line drawn downwards like rotation and translation in a right-handed screw. According to every other theory it will rotate in the opposite direction.

Another experiment has been made by v. Helmholtz,[2] which shows that the potential theory leads to wrong results unless the action of the dielectric is taken into account. *bb* is a rotating conductor, to the ends of which large condenser plates are attached, which, when in rotation, come very near to the similar plates *c*, *c*. The plates *b* and *c* are segments

[1] Pogg., lxiv. 1, 1845. [2] *Wissenschaftliche Abhandlungen*, vol. . 783.

of coaxial cylinders. In v. Helmholtz's experiments bb was rotated between the poles of a powerful electromagnet. The plates c, c were connected with a commutator, which put them to earth when the rotating piece was in the position A, and to the plates of a Kohlrausch condenser when it was in the position B. Now suppose there is a difference of potential between b and c; suppose, for clearness, that b is at a higher potential than c, then when the rotating piece is in the position A the positive electricity goes to earth, and the negative is left to go to the Kohlrausch condenser, when the rotating piece gets to the position B. The change in this condenser was measured by a quadrant electrometer. v. Helmholtz found that the needle of the electrometer was deflected when the piece bb was rotating. Since everything is symmetrical about the axis of rotation, there would be no difference of potential between the



plates b and c, according to the potential law, if we neglect the action of the dielectric. According to Ampère's law there will be a difference of potential between b and c equal to $\Theta a\omega$, where a is the radius of the rotating piece, ω its angular velocity, and Θ the vector potential along the direction of motion of the disc. According to the dielectric theory there will also be the same difference of potential between b and c if we suppose that there is no discontinuity in the motion. We shall suppose that, instead of the velocity changing abruptly from ωa to zero as we pass from the rotating conductor to the dielectric, there is a layer of the dielectric next to the conductor in which the change of velocity is very rapid, one side of the layer moving with the velocity ωa, the other side being at rest. Then, using the same notation as before, we have—

$$X = c\frac{dy}{dt} - b\frac{dz}{dt} - \frac{d}{dx}\left\{F\frac{dx}{dt} + G\frac{dy}{dt} + H\frac{dz}{dt}\right\},$$

$$Y = a\frac{dz}{dt} - c\frac{dx}{dt} - \frac{d}{dy}\left\{F\frac{dx}{dt} + G\frac{dy}{dt} + H\frac{dz}{dt}\right\}.$$

Integrating across the thin layer of the dielectric, in which the velocity is changing rapidly, we see that the difference of potential between b and c equals

$$F\frac{dx}{dt} + G\frac{dy}{dt} + H\frac{dz}{dt},$$

where dx/dt, dy/dt, dz/dt are the velocities of a point on the boundary

of the moving conductor. This equals $\Theta a\omega$, the same value as that given by Ampère's theory, so that in this case the two theories lead to identical results, which are in agreement with the result of Helmholtz's experiments.

Rontgen has recently published[1] a preliminary account of some experiments which seem to prove directly that the variations in the dielectric polarisation produce effects analogous to those due to a current.

This completes the account of the experiments which have been made to test the various theories. As the result of them we may say that they show that it is necessary to take into account the action of the dielectric, but they tell us nothing as to whether any special form of the dielectric theory, such as Maxwell's or Helmholtz's, is true or not.

I have described two experiments which would decide whether Maxwell's theory that all circuits are closed is true or not. It seems to me, however, that even if Maxwell's theory be wrong, Helmholtz's is not the only alternative. I have given a sketch of a theory in which I have tried to make as few assumptions as possible; all that I have assumed is that when a dielectric is acted on by a changing electromotive force, it behaves like a conductor conveying a current whose intensity is proportional to the rate of change of the electromotive force. We know from experiment that it produces effects of the same character, and I have assumed as the simplest assumption I could make that for the same dielectric the equivalent current is proportional to the rate of change of the electromotive force, so that equivalent current $= \eta$ (rate of change of electromotive force).

Both Maxwell and Helmholtz assume that η depends only on the specific inductive capacity of the dielectric, but I think it is preferable, until we have more experiments on this point, to look on η as the measure of a new property of a dielectric, and not to assume that it is merely a function of the specific inductive capacity, the only experimental evidence for this being the by no means perfect agreement between the refractive index and the reciprocal of the square root of the specific inductive capacity. To prove Maxwell's theory of closed circuits it would not be sufficient to prove that for one medium, say air, $\eta = \mathrm{K}/4\pi$, for it is quite conceivable that electrical phenomena may be simpler in a dielectric like air, where the electrical behaviour of the ether seems to be but little affected by the presence of the dielectric, than in such a one as glass or other substance possessing a comparatively large specific inductive capacity, when the effect of the ether is seriously modified by the presence of the medium.

Since in the theory I have sketched the values of

$$\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz},$$

and

$$l\,(u_1 - u_2) + m\,(v_1 - v_2) + n\,(w_1 - w_2)$$

are not zero, but arbitrary, inasmuch as they involve η, in order to find the value of the force between two circuits where there is any discontinuity in the currents we shall require to know the value of the quantity k which occurs in v. Helmholtz's theory.

The most pressing need in the theory of electrodynamics seems to

[1] *Phil. Mag.*, May, 1885.

be an experimental investigation of the question of the continuity of these dielectric currents; we have experimental proof that they exist, but we do not know whether Maxwell's assumption that they always form closed circuits with the other currents is true or not. If Maxwell's assumption should turn out to be true, we should have a complete theory of electrical action; if, on the other hand, it should turn out to be wrong, then we should have to go on to determine the quantity k. This quantity is difficult to determine, as its influence on all closed circuits disappears. It influences, as v. Helmholtz has shown, the rate of propagation of the electric potential along conducting wires, and I think we can see that it would influence the time of oscillation of an irregular distribution of electricity over a conducting shell. The easiest way, however, of determining this quantity would seem to be the straightforward one of measuring electrostatically the value of the electromotive force due to a variation in the charge of a condenser; the expression for the vector potential, as we saw on p. 140, involves k, so that if we measure the electromotive force, which is equal to the rate of variation of the vector potential, we shall determine the value of the vector potential, and consequently of k.

APPENDIX I.

Since the Report was written I have had through the kindness of the author an opportunity of seeing the advance proofs of a paper by Professor J. H. Poynting, of Mason's College, Birmingham, 'On the Connexion between Electric Current and the Electric and Magnetic Induction in the Surrounding Medium,' which is about to appear in the 'Philosophical Transactions.'

The views expressed in this paper are rather a new way of looking at Faraday and Maxwell's theory than a new theory of electrodynamic action, as however it brings the action of the dielectric into great prominence it is instructive to consider it.

The paper is largely based on a previous one by the same author on the 'Transference of Energy in the Electromagnetic Field,'[1] it is therefore necessary to give a brief account of this paper.

In it the author shows that the rate of increase of the energy inside any closed surface equals

$$\frac{1}{4\pi}\iint\{l(\mathrm{R}'\beta-\mathrm{Q}'\gamma)+m(\gamma\mathrm{P}'-\alpha\mathrm{R}')+n(\alpha\mathrm{Q}'-\beta\mathrm{P}')\}\,d\mathrm{S},$$

where $d\mathrm{S}$ is an element of surface, l, m, n the direction cosine of the normal to $d\mathrm{S}$, α, β, γ the components of magnetic induction, and P', Q', R' given by the following equations:—

$$\mathrm{P}'=-\frac{d\mathrm{F}}{dt}-\frac{d\psi}{dx},$$

$$\mathrm{Q}'=-\frac{d\mathrm{G}}{dt}-\frac{d\psi}{dy},$$

$$\mathrm{R}'=-\frac{d\mathrm{H}}{dt}-\frac{d\psi}{dz},$$

[1] *Phil. Trans.*, 1884, part ii

where F, G, and H are the components of the vector potential and ψ the electrostatic potential; thus if the medium is at rest P′, Q′, R′ are the components of the electromotive force at the point.

Professor Poynting interprets this equation to mean that the components parallel to the axes of x, y, z of the flow of energy across *each* element of surface are respectively

$$\frac{1}{4\pi}(R'\beta - Q'\gamma),$$

$$\frac{1}{4\pi}(P'\gamma - R'\alpha),$$

$$\frac{1}{4\pi}(Q'\alpha - P'\beta),$$

so that according to this view the energy flows in the direction which is at right angles both to the magnetic and electromotive forces, and in the direction in which a right-handed screw would move if turned round from the positive direction of the electric intensity to the positive direction of the magnetic intensity; the quantity of energy crossing in unit time unit surface at right angles to this direction being

$$\frac{1}{4\pi}\ .\ \text{Electromotive force at the point} \times \text{magnetic force} \times \text{sine of the angle between these forces.}$$

This interpretation of the expression for the variation in the energy seems open to question. In the first place it would seem impossible *à priori* to determine the way in which the energy flows from one part of the field to another by merely differentiating a general expression for the energy in any region with respect to the time, without having any knowledge of the mechanism which produces the phenomena which occur in the electromagnetic field: for although we can by means of Hamilton's or Lagrange's equations deduce from the expression for the energy the forces present in any dynamical system, and therefore the way in which the energy will move, yet for this purpose we require the energy to be expressed in terms of coordinates fixing the system, and it will not do to take any expression which happens to be equal to it. The problem of finding the way in which the energy is transmitted in a system whose mechanism is unknown seems to be an indeterminate one; thus, for example, if the energy inside a closed surface remains constant we cannot unless we know the mechanism of the system tell whether this is because there is no flow of energy either into or out of the surface, or because as much flows in as flows out. The reason for this difference between what we should expect and the result obtained in this paper is not far to seek. Though the increase in the energy inside a closed surface equals

$$\frac{1}{4\pi}\iint\{l\,(R'\beta - Q'\gamma) + \ldots\}\,dS,$$

it does not follow that the components of the flow of energy across *each* element of surface are $(R'\beta - Q'\gamma)/4\pi$, &c., for we can find quantities u, v, w which are of the dimensions of rate of change of energy per unit area, and for which

$$\iint(lu + mv + nw)\,dS = 0.$$

The following values of u, v, w satisfy this condition :—

$$u = \frac{1}{\mu}\left\{ \frac{d^2}{dy\,dt}(\mathrm{FG}) - \frac{d^2}{dz\,dt}(\mathrm{HF}) \right\},$$

$$v = \frac{1}{\mu}\left\{ \frac{d^2}{dz\,dt}(\mathrm{GH}) - \frac{d^2}{dx\,dt}(\mathrm{FG}) \right\},$$

$$w = \frac{1}{\mu}\left\{ \frac{d^2}{dx\,dt}(\mathrm{HF}) - \frac{d^2}{dy\,dt}(\mathrm{GH}) \right\},$$

where μ is the magnetic permeability and F, G, H are the components of the vector potential, or if ψ be the electrostatic potential

$$u = \frac{d}{dy}\left\{ \frac{d\psi}{dz}\mathrm{H} \right\} - \frac{d}{dz}\left\{ \frac{d\psi}{dy}\mathrm{G} \right\},$$

$$v = \frac{d}{dz}\left\{ \frac{d\psi}{dx}\mathrm{F} \right\} - \frac{d}{dx}\left\{ \frac{d\psi}{dz}\mathrm{H} \right\},$$

$$w = \frac{d}{dx}\left\{ \frac{d\psi}{dy}\mathrm{G} \right\} - \frac{d}{dy}\left\{ \frac{d\psi}{dx}\mathrm{F} \right\},$$

If the values of u, v, w which satisfy these conditions be denoted by the (u_1, v_1, w_1), (u_2, v_2, w_2) . . . then the flow across any element of surface might have for its x component—

$$\frac{1}{4\mu}(\mathrm{R}'\beta - \mathrm{Q}'\gamma) + \lambda_1 u_1 + \lambda_2 u_2 + \lambda_3 u_3 + \ . \ . \ .$$

where $\lambda_1, \lambda_2, \lambda_3$ are arbitrary constants, thus we see that the components of the flow of energy, instead of being uniquely determined by this process are really left quite indeterminate by it. Though this is so, it is very instructive to follow Professor Poynting's description of the way in which the energy flows in some special cases; we shall select a very simple one, the case of a current flowing along a straight wire. Here the lines of electromotive force are straight lines parallel to the wire, the lines of magnetic force are circles with their centres on the wire, and their planes at right angles to it. Then, since according to the view expressed in the paper, the energy moves at right angles both to the electric and magnetic forces, it must in this case move radially inwards to the wire where it is converted into heat. The energy, instead of being supposed to be transmitted through the wire, is regarded as transmitted by the dielectric; and though we may not regard the exact law of flow of the energy as established, still it is very important that this view should be brought into prominence. Another important point brought prominently forward in this paper is the view that magnetic force is always the sign of transference of energy, according to Professor Poynting; indeed, there must be transference of energy from one part of the field to another to give rise to magnetic force. Thus, according to his view, no magnetic force would be exerted by the discharge of a leaky condenser, because in this case he considers the energy to be confined to the space between the plates of the condenser and to be converted into heat where it stands. If the plates were connected by a metallic wire, the energy could flow out and be converted into heat in the wire and this motion of energy would give rise to magnetic forces, so that magnetic

forces would be produced by the discharge of a condenser in this way, but not by leakage. In this case the theory differs from Maxwell's, as according to that theory the alteration in the electromotive force would produce magnetic forces in either case.

In Professor Poynting's second paper, which we have already mentioned, the fundamental principles of electrodynamics are described as the results of the motion of the tubes of electromotive and magnetic force. Maxwell develops electrodynamics from the principles :—

1st. That the total electromotive force round any closed curve is equal to the rate of decrease of the total magnetic induction through the curve.

2nd. The line integral of the magnetic force round any closed curve is equal to 4π times the current through the curve.

Professor Poynting restates these principles in the following way :—

1. 'Whenever electromotive force is produced by change in the magnetic field, or by motion of matter through the field, the E.M.F. per unit length is equal to the number of tubes of magnetic induction cutting or cut by the unit length per second, the E.M.F tending to produce induction in the direction in which a right-handed screw would move if turned round from the direction of motion relatively to the tubes towards the direction of the magnetic induction.'

The second principle he states in the following way :—

'Whenever magnetomotive force is produced by change in the electric field, or by motion of matter through the field, the magnetomotive force per unit length is equal to 4π times the number of tubes of electric induction cutting or cut by unit length per second, the magnetomotive force tending to produce induction in the direction in which a right-handed screw would move if turned round from the direction of the electric induction towards the direction of motion of the unit length relatively to the tubes of induction.'

By magnetomotive force is meant the line integral of the magnetomotive force round a tube of induction. This statement includes the more special one that the line integral of the magnetic force round any closed curve is equal to 4π times the number of tubes passing in or out through the curve per second.

The development of these principles leads to equations which are practically the same as those obtained by Maxwell, the chief difference being that the quantity corresponding to Maxwell's J is no longer arbitrary or rather redundant.

Professor Poynting also introduces into his equations the time integrals of the components of the magnetic force as fundamental quantities, and regards the components of the magnetic as the differential coefficients of these quantities with regard to the time. This method of representing magnetic force was also used by Professor Fitzgerald in his paper on the Electromagnetic Theory of the Reflection and Refraction of Light.[1] It has the advantage of calling attention to the dynamic character of magnetic phenomena. In Professor Poynting's paper some of the applications of his method of regarding electrical phenomena are worked out with great detail for some of the simpler cases.

[1] *Phil. Trans.*, 1880, part ii.

APPENDIX II.

ON THE STRESS IN THE DIELECTRIC.

In the preceding Report we have had so frequently to refer to the action of the dielectric that it may be convenient to give a very brief account of the work which has been done on the stresses which are supposed to exist in it. We shall confine ourselves to the work which has been done on the stresses in the electrostatic field; those existing in the electromagnetic field are of a similar nature, so that any remark applying to one will also apply to the other. The idea of explaining the forces in the electrostatic field by means of stresses in the dielectric seems to be due to Faraday, who describes [1] the stress in the medium by saying that the lines of force tend to contract and also to repel one another. The magnitude and distribution of this stress was investigated by Maxwell; [2] he found that in a medium whose specific inductive capacity was K, and at a point where the electromotive force is R, a tension equal to $KR^2/8\pi$ per unit area along the lines of force combined with a pressure of the same amount at right angles to these, would produce the effects observed in the electrostatic field, that is, at a point in a dielectric, the resultant of these stresses would be a force whose components, parallel to the axes of x, y, z, are eX, eY, eZ respectively, e being the charge of electricity at the point, and X, Y, Z the components of the electromotive force. It may be observed that this system of stress could not be produced by the strain in an elastic solid at rest: this points to the kinetic origin of electrostatic phenomena.

These stresses are in equilibrium at a point in a dielectric where there is no free electricity. At the junction of two media, whose specific inductive capacities are K_1 and K_2, and in which the electromotive forces are R_1 and R_2, and whose interface is perpendicular to the lines of forces, the stresses are not in equilibrium, but there is an unbalanced stress $(K_1 R_1^2 - K_2 R_2^2)/8\pi$ which will tend to make the boundary move towards the medium whose specific inductive capacity is K_1; if these dielectrics are liquids, their interface may become curved so that the forces due to surface tension balance this stress.

Quincke,[3] who has experimentally investigated the effects of electrification on various dielectrics, such, for example, as the effects on the glass of a Leyden jar, has found that the effects on different bodies are very different; he finds, for example, that though the effect of the electrification on the dielectric of the Leyden jar is generally to produce an expansion, yet in some substances, such as the fatty oils, contraction takes place.[4] This diversity in the effects of electrification on different dielectrics shows that the distribution of stress cannot be so simple as was supposed by Maxwell. It also shows that there must be forces in the electric field which are not recognised either by Maxwell's theory or the theory of action at a distance. More general theories have been given in order to meet this difficulty.

[1] *Experimental Researches*, § 1297.

[2] *Electricity and Magnetism*, 2nd edition, p. 149.

[3] *Wied. Ann.*, x. pp. 161, 374, 513; *Ibid.*, ix. p. 105; *Phil. Mag.*, vol. x. p. 30 (1880).

[4] The fatty oils are also an exception to the rule that the index of refraction equals the square root of the specific inductive capacity.

v. Helmholtz [1] has supposed that a change in the density of a dielectric might alter its specific inductive capacity, and he has investigated the consequences of this supposition. Korteweg and Lorberg [2] have investigated the more general case, when the specific inductive capacity of a strained dielectric is supposed to be a function of the strains. Korteweg supposes that if the body suffers dilatation e along the lines of force, and dilatations f and g at right angles to them, then the specific inductive capacity $= \mathrm{K} - \alpha e - \beta\ (f+g)$. Helmholtz assumed that $\alpha = \beta$. The presence of strain in a dielectric must influence the specific inductive capacity, for Quincke has shown that the various coefficients of elasticity are altered under the influence of electricity. Lorberg, l.c., has found the distribution of stress in the medium when the specific inductive capacity alters in this way. He finds that there is a tension along the line of force equal to

$$\left(\frac{\mathrm{K}}{8\pi} + \frac{\alpha}{2}\right) \mathrm{R}^2$$

and a pressure at right angles to them equal to

$$\left(\frac{\mathrm{K}}{8\pi} - \frac{\beta}{2}\right) \mathrm{R}^2$$

The force in the medium parallel to the axis of x

$$= - \rho \frac{d\phi}{dx} + \mathrm{A}$$

where

$$\mathrm{A} = - \frac{\mathrm{R}^2}{4\pi} \frac{d\mathrm{K}}{dx} + \frac{d}{dx} (\beta\, \mathrm{R}^2) + \frac{d}{dx} (\alpha - \beta) \frac{d\phi^2}{dx} + \frac{d}{dy} (\alpha - \beta) \frac{d\phi}{dx} \frac{d\phi}{dy}$$
$$+ \frac{d}{dz} (\alpha - \beta) \frac{d\phi}{dx} \frac{d\phi}{dz}$$

Where ϕ is the potential, and ρ the volume density of the free electricity. The part A of this force exists even when there is no free electricity at the place under consideration; if the dielectric were a fluid, these terms would indicate forces tending to move the fluid when placed in a variable electric field; this motion, however, seems not to have been observed. The supposition made by Korteweg and Lorberg is not the most general one that could be made; we might assume that the specific inductive capacity of the strained body became different in different directions, so that the body would behave like a crystal. Dr. Kerr's experiments on the double refraction in liquids placed between the poles of a powerful electrical machine seem to point to this conclusion.

Kirchhoff [3] has made similar assumptions to those of Korteweg and Lorberg on the effect of strain on the specific inductive capacity, and has arrived at similar equations; in the second paper he applies these equations to some cases which Quincke investigated experimentally.

[1] v. Helmholtz, *Wied. Ann.*, xiii. p. 385; *Wissenschaftl. Abh.* vol. i. p. 298.
[2] Korteweg, *Wied. Ann.*, ix. p. 48; Lorberg, *Wied. Ann.*, xxi. p. 300.
[3] *Wied. Ann.*, xxiv. p. 52, 1885; *Ibid.*, xxv. p. 601, 1885.

Second Report of the Committee, consisting of Professor SCHUSTER (*Secretary*), Professor BALFOUR STEWART, Professor STOKES, Mr. G. JOHNSTONE STONEY, Professor Sir H. E. ROSCOE, Captain ABNEY, *and* Mr. G. J. SYMONS, *appointed for the purpose of considering the best methods of recording the direct intensity of Solar Radiation.*

THE Committee, working on the lines of their last report, have given their attention to the best form of a self-recording actinometer, and have come to the following conclusions :—

1. It seems desirable to construct an instrument which would be a modification of Professor Stewart's actinometer adapted for self-registration—the quantity to be observed being, not the rise of temperature of the inclosed thermometer after exposure for a given time, but the excess of its temperature when continuously exposed over the temperature of the envelope.

2. As the grant to the Committee will not admit of the purchase of a heliostat, it will no doubt be possible to procure the loan of such an instrument, and, by making by its means sufficiently numerous comparisons of the instrument proposed by the Committee with an ordinary actinometer, to find whether the arrangement suggested by the Committee is likely to succeed in practice. The Committee would therefore confine their action for the present to the carrying out of such a series of comparisons.

3. The size of the instrument might be the same as that of Professor Stewart's actinometer.

4. The instrument should have a thick metallic enclosure, as in the actinometer above mentioned, and in this enclosure there should be inserted a thermometer to record its temperature. Great pains should therefore be taken to construct this enclosure so that its temperature shall be the same throughout.

5. The interior thermometer should be so constructed as to be readily susceptible of solar influences. It is proposed to make it of dark glass, of such kind as to be a good absorber, and to give it a flattened surface in the direction perpendicular to the light from the hole.

6. It seems desirable to concentrate the sun's light by means of a lens upon the interior thermometer, as in the ordinary instrument. For if there were no lens the hole would require to be large, and it would be more difficult to prevent the heat from the sky around the sun from interfering with the determination. Again, with a lens there would be great facility in adjusting the amount of heat to be received by employing a set of diaphragms. There are thus considerable advantages in a lens, and there does not appear to be any objection to its use.

The Committee have not drawn their grant (20*l.*). They suggest that they be reappointed, and that the unexpended sum of 20*l.* be again placed at their disposal.

Report on Optical Theories.

By R. T. GLAZEBROOK, *M.A., F.R.S.*

DR. LLOYD'S well-known Report on Physical Optics was presented to the Association at its meeting in Dublin in 1834—fifty-one years ago. Since that time the question of double refraction has been treated of very fully by Professor Stokes in the Report for 1862, but unfortunately he confined himself to that one branch of the subject. The years immediately succeeding that in which Dr. Lloyd's report was read were marked by work of great importance, which has formed the basis for much that has since been done, and it is necessary, before writing of recent progress in the subject, to consider somewhat carefully the researches of Green, MacCullagh, Cauchy, and F. Neumann.

This I propose to do, in as brief a manner as possible, for that part of the subject which is not included in Professor Stokes's report. I then propose to go on to the consideration of more modern work, treating separately (1) of the simple elastic solid theory, (2) of theories based on the mutual reactions of matter and ether, (3) of the electro-magnetic theory.

PART I.—INTRODUCTION.

THE WORK OF MACCULLAGH, NEUMANN, GREEN, AND CAUCHY.

Chapter I.—MACCULLAGH.

§ 1. Fresnel[1] himself had developed a theory of reflexion and refraction, and had arrived at formulæ giving the intensities of the reflected and refracted waves in terms of the incident.

In obtaining these he relied on the two following principles :—

The resolved parts of the displacements parallel to the face of incidence are the same in the two media.

The total energy in the reflected and refracted waves is equal to that in the incident wave.

He further supposed that the rigidity of the ether is the same in all transparent media, and hence that reflexion and refraction are produced by a change of density ; from this it follows that the refractive index of a medium is proportional to the square of the density of the ether in the medium. The direction of vibration is considered to be perpendicular to the plane of polarisation. According to this theory there is a discontinuity in the component of the vibration at right angles[2] to the surface.

§ 2. An elegant geometrical expression of the laws to which these principles lead was given by MacCullagh. He defines as the transversal of a ray the line of intersection of the wave front and the plane of polarisation ; the length of this line being proportional to the

[1] Fresnel, *Ann. de Chim. et de Physique*, t. xlvi. p. 225 ; *Œuvres complètes*, t. i. p. 767.

[2] For a further consideration of this point see p. 186.

amplitude of the vibration multiplied by the density of the medium. Then Fresnel's results may be expressed by the statement that the transversal of the incident ray is the resultant, in the mechanical sense of the word, of those of the reflected and refracted rays.

This first suggestion of MacCullagh's was modified by reading some of Cauchy's work on double refraction, from which it appeared possible that the vibrations of polarised light might lie in the plane of polarisation instead of at right angles to it. Adopting, then, this hypothesis, a transversal represents in addition the direction of vibration; and if the further supposition is made that the ether is of the same density in all media, so that reflexion and refraction arise from variations in its rigidity and not in its density, expressions very nearly identical with Fresnel's can be found for the intensities of the reflected and refracted rays, while at the same time the principle of the continuity of the displacement normal to the surface is satisfied.

§ 3. These three principles—

(1) The ether is of the same density in all media,

(2) The displacement is the same on both sides of the surface of separation of the two media,

(3) The energy of the incident wave is equal to that of the reflected and refracted waves

—were applied by MacCullagh to the problem of reflexion and refraction at the surface of a crystal, and the results of a first investigation were communicated to the meeting of the Association in 1834.

The theory as there given was somewhat modified in consequence of a paper by Seebeck in Poggendorff's 'Annalen,' and took its final form in a memoir read before the Irish Academy [1] in January 1837. MacCullagh in this paper states his fundamental principles, not as based on mechanics, but merely as those which had led him to a solution, the results of which agree closely with the experiments of Seebeck and Brewster.

The analysis of the problem is greatly simplified by the introduction of the idea of 'uniradial directions.'

In a crystal, for any given direction of incidence, there are two positions for the incident transversals, which give rise each to only one refracted ray—there are corresponding positions for the reflected transversals. These directions of the incident transversals are the *uniradial* directions.

For a uniradial direction the incident, reflected, and refracted transversals lie in one plane, and the refracted transversal is the resultant of the other two.

The transversal is normal to the plane containing the ray and the wave normal. The polar plane is defined as a plane through the transversal and parallel to the line joining the extremity of the ray to the point in which the wave normal meets the surface of wave slowness, here designated the 'index surface.'

It is hence proved that for a uniradial direction the incident and reflected transversals lie in the polar plane of the refracted ray, and then the principles of equivalence of vibrations and of *vis viva* lead to equations to determine the relation between the azimuths of the transversals referred to the plane of incidence.

[1] MacCullagh, 'On the Laws of Crystalline Reflexion and Refraction,' January, 1837, *Trans. of Royal Irish Academy*, vol. xviii.

These give—

$$\left.\begin{aligned} \tan\theta &= \cos(\phi-\phi')\tan\theta' + \frac{\sin^2\phi'\tan\chi}{\cos\theta'\sin(\phi+\phi')} \\ \tan\theta_1 &= -\cos(\phi+\phi')\tan\theta' + \frac{\sin^2\phi'\tan\chi}{\cos\theta'\sin(\phi-\phi')} \end{aligned}\right\} \quad . \quad (1)$$

with exactly similar formulæ for the other uniradial direction; θ, θ_1, and θ' are the azimuths of the transversals in the incident, reflected, and refracted waves measured from the plane of incidence, and χ the angle between the ray and the wave normal. In the general case the incident vibration is resolved into two in the uniradial directions, and each considered separately. When the two values of θ_1, found from these, are equal, the partial reflected transversals coincide; the value of θ_1 at which this takes place is the deviation, and the angle of incidence the polarising angle.

The theory is applied to Iceland spar, and agrees with experiments of Brewster and Seebeck.

§ 4. The same problem is considered by Neumann [1] in a long paper read in 1835 before the Berlin Academy, and in a second memoir published separately in Berlin [2] in 1837, and the same results deduced from similar hypotheses.

§ 5. In 1839 MacCullagh [3] attempted to found his theory on a dynamical basis by finding an expression for the potential energy of the ether when strained by the passage of the waves of light, and applying to the expressions thus obtained Laplace's principle of virtual velocities.

This leads to a volume integral which holds throughout the space occupied by the medium, and a surface integral to be taken over the boundary.

The surface integral taken in connection with the principle of the continuity of the displacement gives the conditions at the surface, and these are shown to be identical with the conditions found in the previous paper.

Professor Stokes, in the Report on Double Refraction, has pointed out the error in the fundamental expression assumed by MacCullagh for the energy, and this error of course affects the theory of reflexion.

Chapter II.—Green.

§ 1. The correct expression for the energy, and the correct laws of reflexion and refraction on a strict elastic solid theory, had at the date of MacCullagh's paper been given by George Green [4] in a memoir read before the Cambridge Philosophical Society in December 1837.

The potential energy of the medium is shown to be a function (ϕ) of the three principal elongations s_1, s_2, s_3, and the three principal shearing-strains α, β, γ.

[1] Neumann, 'Theoretische Untersuchung der Gesetze nach welchen das Licht an der Gränze zweier vollkommenen durchsichtigen Medien reflectirt und gebrochen wird.'

[2] Neumann, 'Ueber den Einfluss der Krystallflächen bei der Reflexion und über die Intensität des gewöhnlichen und ungewöhnlichen Strahls.' See also 'Vorlesungen über theoretische Optik,' von Dr. F. Neumann, edited by Dr. E. Dorn. Leipzig: 1885.

[3] MacCullagh, 'An Essay towards a Dynamical Theory of Crystalline Reflexion and Refraction,' *Trans. of Royal Irish Academy*, vol. xxi.

[4] Geo. Green, 'On the Laws of Reflexion and Refraction of Light at the Common Surface of two Non-crystallised Media,' *Camb. Phil. Trans.* 1838, and *Papers of the late Geo. Green*, p. 243.

This function is then expanded in the form

$$\phi = \phi_0 + \phi_1 + \phi_2 + \cdot \;.\;.\;.$$

ϕ_0, &c., being homogeneous functions of the orders 0, 1, 2 of the small quantities s_1, s_2, &c.

The equations of motion depend on $\delta\phi$, and so, ϕ_0 being constant, it does not appear. If the medium in its equilibrium position is unstrained ϕ_1 vanishes also, and in general ϕ_2 contains twenty-one arbitrary coefficients. ϕ_3 may be neglected compared with ϕ_2. If the medium be not initially free from strain, ϕ_1 will introduce six more coefficients, so that finally we find the most general form of ϕ for our purposes involves twenty-seven coefficients.[1]

Green then supposes the medium to be symmetrical with regard to three rectangular planes, and obtains finally as the form for ϕ, taking the case in which the medium is initially strained, the value—

$$\begin{aligned} -2\phi = {} & 2\mathrm{A}\frac{du}{dx} + 2\mathrm{B}\frac{dv}{dy} + 2\mathrm{C}\frac{dw}{dz} \\ & + \mathrm{A}\left\{\left(\frac{du}{dx}\right)^2 + \left(\frac{dv}{dx}\right)^2 + \left(\frac{dw}{dx}\right)^2\right\} \\ & + \mathrm{B}\left\{\left(\frac{du}{dy}\right)^2 + \left(\frac{dv}{dy}\right)^2 + \left(\frac{dw}{dy}\right)^2\right\} \\ & + \mathrm{C}\left\{\left(\frac{du}{dz}\right)^2 + \left(\frac{dv}{dz}\right)^2 + \left(\frac{dw}{dz}\right)^2\right\} \\ & + \mathrm{G}\left(\frac{du}{dx}\right)^2 + \mathrm{H}\left(\frac{dv}{dy}\right)^2 + \mathrm{I}\left(\frac{dw}{dz}\right)^2 \\ & + 2\mathrm{P}\frac{dv}{dy}\frac{dw}{dz} + 2\mathrm{Q}\frac{du}{dx}\frac{dw}{dz} + 2\mathrm{R}\frac{du}{dx}\frac{dv}{dy} \\ & + \mathrm{L}\left(\frac{dv}{dz} + \frac{dw}{dy}\right)^2 + \mathrm{M}\left(\frac{du}{dz} + \frac{dw}{dx}\right)^2 + \mathrm{N}\left(\frac{du}{dy} + \frac{dv}{dx}\right)^2 \qquad (1) \end{aligned}$$

If the medium be initially unstrained A=B=C=0, while, further, if it be completely isotropic,

$$\left.\begin{aligned} &\mathrm{G} = \mathrm{H} = \mathrm{I} = 2\mathrm{N} + \mathrm{R} \\ &\mathrm{L} = \mathrm{M} = \mathrm{N} \\ &\mathrm{P} = \mathrm{Q} = \mathrm{R}. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (2)$$

And introducing two new constants, A and B,

$$\begin{aligned} -2\phi_2 = {} & \mathrm{A}\left(\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}\right)^2 \\ & + \mathrm{B}\left\{\left(\frac{du}{dy} + \frac{dv}{dx}\right)^2 + \left(\frac{du}{dz} + \frac{dw}{dx}\right)^2 + \left(\frac{dv}{dz} + \frac{dw}{dy}\right)^2\right. \\ & \left. - 4\left(\frac{dv}{dy}\frac{dw}{dz} + \frac{dw}{dz}\frac{du}{dx} + \frac{du}{dx}\frac{dv}{dy}\right)\right\} \quad . \quad . \quad . \quad . \quad (3) \end{aligned}$$

[1] For the difference between this and Cauchy's theory see Prof. Stokes's report.

According to Green's theory of double refraction, founded simply on the supposition that the displacements are in the wave front in a crystal,

$$\left.\begin{aligned} \mathrm{G}=\mathrm{H}=\mathrm{I}&=\mu, \text{ say} \\ \mathrm{P}&=\mu-2\mathrm{L} \\ \mathrm{Q}&=\mu-2\mathrm{M} \\ \mathrm{R}&=\mu-2\mathrm{N} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (4)$$

The equations of motion are given by

$$\iiint dx\,dy\,dz\left\{\rho\left(\frac{d^2u}{dt^2}\,\delta u+\frac{d^2v}{dt^2}\,\delta v+\frac{d^2w}{dt^2}\,\delta w\right)-\delta\phi\right\}=0 \quad . \quad . \quad (5)$$

In treating of the problem of reflexion this integral is applied to the whole of the two media, and is transformed by partial integration into a volume integral, which may be written

$$\iiint dx\,dy\,dz\left\{\left(\rho\frac{d^2u}{dt^2}-\mathrm{X}\right)\delta u+\left(\rho\frac{d^2v}{dt^2}-\mathrm{Y}\right)dv+\left(\rho\frac{d^2w}{dt^2}-\mathrm{Z}\right)\delta w,\right.$$

and a surface integral, which we may write

$$\begin{aligned} \iint & dy\,dz\,(\overline{\mathrm{X}}\,\delta u-\overline{\mathrm{X}}_1\,\delta u_1) \\ & +dz\,dx\,(\overline{\mathrm{Y}}\,\delta v-\overline{\mathrm{Y}}_1\,\delta v_1) \\ & +dx\,dy\,(\overline{\mathrm{Z}}\,\delta w-\overline{\mathrm{Z}}_1\,\delta w_1). \end{aligned}$$

These two integrals must vanish separately. Green's work as to the former, on which the propagation of light depends, has been considered by Professor Stokes. It leads to the three equations—

$$\left.\begin{aligned} \rho\frac{d^2u}{dt^2}&=(\mathrm{A}-\mathrm{B})\frac{d}{dx}\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)+\mathrm{B}\nabla^2u \\ \rho\frac{d^2v}{dt^2}&=(\mathrm{A}-\mathrm{B})\frac{d}{dy}\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)+\mathrm{B}\nabla^2v \\ \rho\frac{d^2w}{dt^2}&=(\mathrm{A}-\mathrm{B})\frac{d}{dz}\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)+\mathrm{B}\nabla^2w \end{aligned}\right\} \quad . \quad . \quad (6)$$

which form the basis of the whole theory of isotropic elastic solids.

§ 2. The latter integral equated to zero gives us the surface conditions; for over the surface, according to Green, who treats the ether in the two media as two separate elastic solids always in contact with each other, we must have

$$u=u_1,\ v=v_1,\ w=w_1, \quad . \quad . \quad . \quad . \quad (7)$$

and hence

$$\overline{\mathrm{X}}=\overline{\mathrm{X}}_1,\ \overline{\mathrm{Y}}=\overline{\mathrm{Y}}_1,\ \overline{\mathrm{Z}}=\overline{\mathrm{Z}}_1, \quad . \quad . \quad . \quad . \quad (8)$$

These six equations determine the motion completely.

Using Green's notation, and considering only the case of two homogeneous media, let us take the plane $x=0$ as the separating surface. Then the surface conditions become

$$u=u_1,\ v=v_1,\ w=w_1,$$

$$\left.\begin{aligned}
&A\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)-2B\left(\frac{dv}{dy}+\frac{dw}{dz}\right)\\
&=A_1\left(\frac{du_1}{dx}+\frac{dv_1}{dy}+\frac{dw_1}{dz}\right)-2B_1\left(\frac{dv_1}{dy}+\frac{dw_1}{dz}\right)\\
&B\left(\frac{du}{dy}+\frac{dv}{dx}\right)=B_1\left(\frac{du_1}{dy}+\frac{dv_1}{dx}\right)\\
&B\left(\frac{du}{dz}+\frac{dw}{dx}\right)=B_1\left(\frac{du_1}{dz}+\frac{dw_1}{dx}\right)
\end{aligned}\right\} \quad . \quad . \quad . \quad (9)$$

when $x=0$.

The problem now resolves itself into two cases. Let us take the plane of incidence as the plane xy, and suppose that the vibrations in the incident wave are perpendicular to this, then—

CASE I.—Light polarised in the plane of incidence,

$$u=u_1=v=v_1=0,$$

and the conditions are

$$\left.\begin{aligned} w&=w_1\\ B\frac{dw}{dx}&=B_1\frac{dw_1}{dx}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Now, we have seen that Fresnel originally assumed that the rigidity of the ether is the same in all media, and the density different. Green, adopting this view, puts $B=B_1$, $A=A_1$,* and the above formulæ lead him to results agreeing with those given by Fresnel's simple theory for this case, while, by making the angle of refraction imaginary, it is shown that the wave, when totally reflected, undergoes just the change of phase given by Fresnel.

CASE II.—Light polarised at right angles to the plane of incidence, the vibrations being therefore in that plane.

Then $w=w_1=0$, and the surface conditions are

$$u=u_1,\ v=v_1,$$

$$\left.\begin{aligned}
A\left(\frac{du}{dx}+\frac{dv}{dy}\right)-2B\frac{dv}{dy}&=A_1\left(\frac{du_1}{dx}+\frac{dv_1}{dy}\right)-2B_1\frac{dv_1}{dy}\\
B\left(\frac{du}{dy}+\frac{dv}{dx}\right)&=B_1\left(\frac{du_1}{dy}+\frac{dv_1}{dx}\right)
\end{aligned}\right\} \quad . \quad (11)$$

We have here four equations to determine two unknowns, viz. the intensities of the reflected and refracted rays, and it is clear, therefore, that two more quantities must come under consideration.

Now, in the general case it follows from the equations of motion given above that two waves can traverse the medium. In the one of these the vibrations are transverse, and travel with the velocity $\sqrt{B/\rho}$. This constitutes the light-wave. In the other the vibrations are longitudinal, and travel with the velocity $\sqrt{A/\rho}$. In the case before us, then, reflexion gives rise to both these, and we have two reflected and two refracted waves. But experi-

* The physical meaning of these constants and the relations implied by these conditions will be considered later, see p. 167.

ment tells us, to a high degree of approximation, that the whole of the energy of the incident light appears in the reflected and refracted light. We are therefore forced to suppose not merely that the longitudinal wave does not affect our eyes as light, but also that it does not absorb any material part of the incident energy. This conclusion is confirmed when we recollect that on arriving at a second refracting surface this longitudinal wave would, if it existed, set up transverse vibrations which would be visible, so that on passing through a prism, for example, there would always be two emergent rays.

Now, Green shows that very little energy will be absorbed by the longitudinal vibrations, provided that the ratio A/B be very small or very great; and, further, that the condition of stability of the medium requires that A/B should be greater than 4/3. He therefore concludes that A/B is very great—practically infinite, or that the wave of longitudinal vibrations travels with a velocity enormously greater than that of light.

The equations are then solved, assuming that $B=B_1$ and $A=A_1$,* by the substitutions—

$$\left.\begin{aligned} u &= \frac{d\phi}{dx} + \frac{d\psi}{dy} \\ v &= \frac{d\phi}{dy} - \frac{d\psi}{dx} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (12)$$

The symbol ϕ represents the longitudinal or, as Sir Wm. Thomson has called it, the pressural wave, and ψ the transverse or light wave.

It is shown that by the reflexion a difference of phase is produced between the reflected and incident and the refracted and incident waves, and expressions are found for the intensities of the reflected and refracted waves in terms of that of the incident. According to these expressions, the intensity of the reflected wave never vanishes, but reaches a minimum when $\varphi + \phi' = 90°$. The minimum value of the ratio of the two intensities will be for air and water about 1/151, while for a diamond or other substance of great refractive index it would be much greater still.

§ 3. This result, then, of the theory is in direct antagonism to the fact that light is very nearly completely polarised by reflexion from most transparent surfaces at the polarising angle, while the values found for the change of phase do not agree with the experiments of Jamin,[1] Quincke, and others, and the theory as left by Green is certainly incorrect. We shall, however, return to this point later.[2]

Green does not apply his equations to the problem of crystalline reflexion, and, indeed, his theories of reflexion and of double refraction are entirely inconsistent, for the former supposes the ether to have the same rigidity in all bodies, while the latter attempts to explain double refraction by making the rigidity of a crystal a function of the direction of the strain.

* This last equation, as we shall see later, is not necessary.

[1] Jamin, *Ann. de Chimie* (3), t. xxix. p. 263; Quincke, 'Experimentelle optische Untersuchungen,' *Pogg. Ann.* See also Haughton, *Phil. Mag.* (4), vol. vi. p. 81.

[2] See p. 192.

Chapter III.—Cauchy.

§ 1. Cauchy's optical researches were being published about this same period, and a very full and interesting account of them, and of the work of other French authors, is given by M. de St. Venant in a paper to which I am greatly indebted for much valuable information.[1]

Cauchy's work on elastic solids began in 1822, and in 1829 he presented to the Academy his first memoir on isotropic media. His more generally known memoir followed in 1830,[2] containing his work on double refraction and the propagation of light in a crystal. An account of this is given in Professor Stokes's report in 1862. His first work on dispersion, which he explained (following a suggestion of Coriolis) by the addition of terms involving differential coefficients above the second, was published in 1830.[3] The great memoir, 'Sur la dispersion de la lumière,' in which he developed this principle, appeared between 1830 and 1836;[4] and in this same memoir he first considered the problem of reflexion and refraction, which led him to the idea of elliptic polarisation and a more general expression for the possible displacements of a molecule[5] in a plane wave.

§ 2. Further considerations on the subject of reflexion and refraction led him to conclude that, in order to obtain Fresnel's expressions for the intensities of the reflected and refracted rays in terms of that of the incident, it was necessary that not only the displacements, but their differential coefficients with respect to the normal to the surface of separation, should be continuous across that surface. This continuity had to be rendered compatible with the rest of his theory, in which the ether is considered as differing both in density and elasticity in different media.[6] It is, however, quite inconsistent with the true surface conditions established by Green, Neumann, and MacCullagh on their various hypotheses—the conditions, namely, that the displacements and the stresses over the surface should be the same in the two media; and Cauchy, in consequence, was led to conclude that the method of Lagrange, by which the above conditions were first established, is inapplicable to questions of this kind.[7] But, as St. Venant points out, these surface conditions do not in the least depend on Lagrange's method of virtual velocities, but on the fundamental elementary principles of mechanics, and can never be reconciled with Cauchy's theory of continuity so long as it is supposed that the rigidity of the ether varies from one body to another.

§ 3. In 1839[8] Cauchy re-established his equations of motion for an isotropic medium, basing them on analytical considerations of symmetry. For a perfectly isotropic body he arrived at the equations—

$$\rho \frac{d^2u}{dt^2} = (\mathrm{A}-\mathrm{B})\frac{d\theta}{dx} + \mathrm{B}\nabla^2 u \qquad . \quad . \quad . \quad (13)$$

&c., where
$$\theta = \frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz},$$

[1] De St. Venant, 'Sur les diverses manières de présenter la théorie des ondes lumineuses,' *Ann. de Chimie* (S. iv.), t. xxv. p. 335.

[2] Cauchy, *Exercices de Mathématiques*, t. v. pp. 19–72.

[3] Cauchy, *Bulletin de M. de Ferussac*, t. xv. p. 9.

[4] *Nouveaux Exercices de Mathématiques.*

[5] *C. R.* t. vii. p. 867.

[6] *C. R.* t. viii. p. 374; t. x. p. 266.

[7] *C. R.* t. xxvii. p. 100; t. xvi. p. 154; t. xxviii. pp. 27, 60.

[8] *C. R.* t. viii. p. 985; *Exercices d'Analyse*, t. i. p. 101.

already given by Green.[1] And in cases in which the axes can only be turned together about the origin, a third coefficient comes in, in the form of terms, such as

$$C\left(\frac{dw}{dy}-\frac{dv}{dz}\right).$$

In 1849[2] Cauchy propounded the idea that the ether atoms in a body such as a crystal are disposed, as it were, in shells round the matter atoms in such a manner as to have different elastic properties at different points of the same shell; the shells, however, are regularly placed, and the properties of the ether repeat themselves at similar points in the different shells. It results from this that the constants in the equations of motion will be periodic functions of the equilibrium positions of the molecules, and for optical effects we have to do with the average displacement over a small volume of the medium.[3]

The general equations established by Cauchy lead to a normal wave travelling with a velocity equal to $\sqrt{A/\rho}$. According to his earlier theory, resting on the law of action between the molecules of ether, A and B are not independent, and it is possible by suitably choosing the law of force to make A vanish or even be negative. The theory[4] of reflexion and refraction led him to conclude that A was a small negative quantity, so that the normal disturbance ceases to be propagated as such.

§ 4. Cauchy's work was continued by Briot,[5] starting from the equations of motion deduced from the mutual action between two particles of ether, and the supposition suggested by Cauchy that the ether within a crystal is in a state of unequal strain. In treating of dispersion Briot points out that it cannot be explained in the manner originally suggested by Cauchy, for there is no reason why the terms in his differential equations from which it arises should be insensible in a vacuum if they are sensible in ordinary transparent media. He therefore makes it depend on terms arising from a periodic distribution of the ether within material bodies, and shows that to obtain Cauchy's dispersion formula the law of action between the molecules must be as the inverse sixth power of the distance. In his memoir on reflexion and refraction, however, he adopts Cauchy's views as to the disappearance of the normal wave, and this is quite inconsistent with the above law, while the ether and matter molecules must attract each other with a force varying as the inverse square of the distance.

§ 5. The problem of reflexion and refraction for both isotropic and crystalline bodies is treated of in a memoir published in 1866–67,[6] starting from Cauchy's principle of continuity, to which he gives an extended meaning in the second memoir. He at first supposes the vibrations in the crystal to be rigorously in the plane of the wave, and, adopting MacCullagh's methods of the uniradial direction, arrives at his equations. The work is then extended to the general case in which the vibrations

[1] See p. 161.
[2] *C. R.* t. xxix. pp. 641, 644, 728, 762; t. xxx. p. 27.
[3] For the further development of this by M. Sarrau, see p. 174.
[4] *C. R.* t. ix. pp. 677, 727, 765. On this point cf. Green's theory. See also Stokes's, *Brit. Assoc. Report*, 1862, and pp. 170–195.
[5] Briot, *Essais sur la théorie mathématique de la lumière.* Paris, 1864.
[6] *Liouville's Journal*, t. xi. p. 305; t. xii. p. 185.

are quasi-transversal, and it is shown how the simpler forms of the equations are modified by this.

Thus, for the uniradial directions in the case in which the longitudinal disturbance is supposed to be strictly normal to the wave, if χ is the angle between the ray and the wave normal, θ, θ', and θ_1 the azimuths of the planes of polarisation, measured from the plane of incidence, of the incident reflected and refracted waves, ϕ and ϕ' the angles of incidence and refraction, and m a quantity depending on the angle between the plane of the wave and the direction of vibration, then—

$$\left.\begin{aligned}\tan\,\theta &= \tan\,\theta'\cos\,(\phi - \phi') + \frac{m\,\sin^2\,\phi'\,\tan\,\chi}{\cos\,\theta'\,\sin\,(\phi + \phi')}\\ \tan\,\theta_1 &= \tan\,\theta'\cos\,(\phi + \phi') - \frac{m\,\sin^2\,\phi'\,\tan\,\chi}{\cos\,\theta'\,\sin\,(\phi - \phi')}\end{aligned}\right\} \quad . \quad (14)$$

These formulæ agree with those of MacCullagh if we put $m = 1$.

Chapter IV.—Elliptic Polarisation. Comparison of Results.

§ 1. The peculiar phenomena presented by quartz had been explained by Airy in 1831 [1] on the assumption that the two waves were elliptically polarised. In 1836 [2] MacCullagh made a further advance, and showed how the addition of certain terms to the differential equations of motion would lead to the elliptic polarisation required by Airy's theory. The equations assumed by MacCullagh, for the existence of which he does not attempt to assign a mechanical reason, were—

$$\left.\begin{aligned}\frac{d^2u}{dt^2} &= A\frac{d^2u}{dz^2} + C\frac{d^3v}{dz^3}\\ \frac{d^2v}{dt^2} &= B\frac{d^2v}{dz^2} - C\frac{d^3u}{dz^3}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (15)$$

Where $A = a^2$, $B = a^2 - (a^2 - b^2)\sin^2\theta$,

a and b being constants, and θ the angle between the optic axis and the wave normal—the axis of z. The two waves resulting from these equations are shown to be elliptically polarised, while their velocity is given by the equation

$$(w^2 - A)\,(w^2 - B) = \frac{4\pi^2C^2}{\lambda^2} \quad . \quad . \quad . \quad . \quad (16)$$

λ being the wave length. The rotation of the plane of polarisation produced by the passage of a plane polarised ray through a plate of crystal cut at right angles to the axis, and of unit thickness, is $2\pi^2C/a^4\lambda^2$.

MacCullagh shows that the results of this hypothesis as to the form of the equations agree fairly with Airy's experiments, and that the agreement would be made somewhat more close by the hypothesis that C varies slightly with θ.

[1] Airy, 'On the Nature of the Two Rays produced by the Double Refraction of Quartz,' *Camb. Phil. Soc. Trans.* vol. iv. pp. 79, 198.

[2] MacCullagh, 'On the Laws of the Double Refraction of Quartz,' *Irish Trans.* vol. xvii. p. 461.

§ 2. Terms of a similar kind were first applied by Airy [1] to explain the magnetic rotation of the plane of polarisation discovered by Faraday. Airy starts by calling attention to the fundamental difference between the rotation produced by quartz and that due to magnetic action. In quartz, sugar, etc., by reflecting the ray back along its original path the rotation is reversed, so that the ray emerges with its plane of polarisation unaltered, while in bodies under magnetic action the rotation is doubled by the same process. It is as if the former effect were due to a heliacal arrangement of the molecules, the latter to a continuous rotation of them round the lines of force. Airy shows that the effects produced can be accounted for by the introduction into the equation for u of terms involving odd differential coefficients of v with respect to the time, and he works out the case in which the equations are

$$\left.\begin{aligned}\frac{d^2u}{dt^2} &= A\frac{d^2u}{dz^2} + C\frac{dv}{dt}\\ \frac{d^2v}{dt^2} &= A\frac{d^2v}{dz^2} - C\frac{du}{dt}\end{aligned}\right\} \quad . \quad . \quad . \quad (17)$$

The two possible velocities for a wave of period τ are given by

$$v_1{}^2 = \frac{A}{1+\frac{\tau}{2\pi}C}, \qquad v_2{}^2 = \frac{A}{1-\frac{\tau}{2\pi}C}.$$

It is pointed out also that terms such as $\dfrac{d^3v}{dz^2dt}$ or $\dfrac{d^3v}{dt^3}$ would also lead to the effect observed; though they would differ in the law, expressing the relation between the velocity and the wave length. Airy remarks that 'the equations are given, not as offering a mechanical explanation of the phenomena, but as showing that they may be explained by equations, which equations appear such as might be introduced by some plausible mechanical assumption.'

§ 3. The attempt to estimate the relative value of the theories of reflexion and refraction just developed is rendered easier if we consider the physical meaning of the two constants involved. The importance of this has been continually insisted upon by Sir Wm. Thomson [2] in his numerous writings on the subject of elasticity, which have done so much to clear away difficulties and obscurities; and though these writings belong to the later period of our subject, we shall consider here some of the results they lead to.

To Green, Cauchy, and MacCullagh, A and B are constants, appearing in the most general form of the equations, and on which the rate of propagation of waves depends; their connection with the other physical properties of the solids is not considered. Now an isotropic elastic solid is one which possesses the power of opposing resistance (1) to change of shape, (2) to change of volume, and has in consequence only two principal moduluses of elasticity.

[1] Airy, 'On the Equations applying to Light under the Action of Magnetism,' *Phil. Mag.* (3), vol. xxviii. p. 469.

[2] See especially, Thomson, 'Elements of a Mathematical Theory of Elasticity,' *Phil. Trans.* 1856, p. 481; Thomson and Tait, *A Treatise on Natural Philosophy*, vol. i.; Thomson, article 'Elasticity,' *Encyclopædia Britannica*, ninth edition, 1880.

On the value of the one, the rigidity, n, in the notation of Thomson and Tait, depends the resistance which the body can oppose to a stress tending to produce distortion or change of shape without change of volume, and it is measured by the ratio of the shearing stress—or stress tending to produce distortion—to the strain or alteration of shape produced. It can be shown that this is equal to the constant, B, of Green's theory. And the velocity of a wave of transverse displacement, since it does not produce changes in the volume of the body through which it passes, depends only on the ratio of the rigidity to the density.

On the value of the other principal modulus depends the resistance which the body can offer to compression or change of volume when subjected to a uniform hydrostatic pressure at all points of its surface. The compression produced is measured by the ratio of the change in volume to the original volume, and the modulus of compression, k, is the ratio of the stress to the compression it produces.

It has been shown by Thomson that the relation between A and the principal moduluses is given by the equation $A = k + \frac{4}{3}n$, so that k, the modulus of compression, is equal to $A - \frac{4}{3}B$.

The expression for the stresses arising from simple elongations e, f, g in the directions of the axes, and from simple shears α, β, γ round the axes, are found; they are

$$\begin{aligned} N_1 &= (k + \tfrac{4}{3}n)e + (k - \tfrac{2}{3}n)(f + g) \\ &= (k + \tfrac{4}{3}n)(e + f + g) - 2n(f + g) \\ &= A\left(\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}\right) - 2B\left(\frac{dv}{dy} + \frac{dw}{dz}\right), \end{aligned}$$

etc., using Green's notation, and

$$T_3 = n\alpha = B\left(\frac{dv}{dz} + \frac{dw}{dy}\right),$$

etc., and from these Green's expression for the energy can be obtained. We may note that the velocity of propagation of the longitudinal waves $\sqrt{A/\rho}$ depends on both the modulus of compression and the rigidity.

According to the mathematical theories of Navier, Poisson, Cauchy, and De St. Venant, there is a definite relation between n and k for all bodies given by the equation $n = \frac{3}{5}k$ or $B = \frac{1}{3}A$. Stokes[1] was the first to point out that this could not be true universally, and this conclusion has been confirmed by the experiments of Wertheim and Kirchhoff for various metals.

Thus, on the assumption that the properties of the ether are those of an elastic solid, Cauchy's theory in its original form, independently of the consideration of his surface conditions, must be rejected. In his later theory, as we have said, he does admit the second constant A.[2] But, we have seen that the existence of the two constants A and B implies that there will be two waves in the medium, while the absence of the wave of normal vibrations in light, combined with the conditions of stability, requires that A should be great compared with B, and this again requires that k, the modulus of compression, should be great compared with n, the

[1] Stokes, 'On the Friction of Fluids in Motion and the Equilibrium and Motion of Elastic Solids,' *Trans. Camb. Phil. Soc.* 1845; *Math. Papers*, i. p. 75.

[2] See pp. 164, etc.

rigidity. Thus we are compelled to treat the ether as an elastic solid of very great—practically infinite—incompressibility. Now, the cubical dilatation produced by a given state of strain is measured by $e+f+g$, or $\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}$, and the condition of incompressibility requires that this should be zero. It is not, however, admissible to omit the terms in $e+f+g$ in the equations, for they occur with the constant A as a factor, and the physical condition that these terms should vanish implies also that A should be very large. To obtain the correct equations we must put

$$(\mathrm{A}-\mathrm{B})\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)=-p,$$

and they then become

$$\rho\frac{d^2u}{dt^2}=-\frac{dp}{dx}+\mathrm{B}\nabla^2u. \qquad (18)$$

et cetera.

§ 4. MacCullagh and Neumann omit the terms in p entirely from their equations, both within the medium and over the surface, and are led in consequence to erroneous results, though, as we shall see later, their theories (modified so as to include the terms) have been developed by Lord Rayleigh[1] and Lorenz. Green, as we have seen, is perfectly consistent throughout; but his final equations, unfortunately, are not confirmed by experiment. If we assume the rigidity of the ether to be the same in the two media, it is not difficult to show that Cauchy's surface conditions are identical with those of Green, or, to be more accurate, that Green's correct equations expressing the continuity of the stress and of the displacement over the surface reduce to Cauchy's. Green obtains his surface condition from the value of a certain integral over the surface; they may be obtained, perhaps more simply, from the equations of motion of an element $d\mathrm{S}$ of the surface; for, taking the case when the plane $x=0$ is the bounding surface, let ν be the thickness of the element, N_1, N_1' the stresses on it parallel to the axis of x, then we have

$$\rho\nu\, d\mathrm{S}\frac{d^2u}{dt^2}=(\mathrm{N}_1-\mathrm{N}_1')\,d\mathrm{S} \qquad (19)$$

Hence, when ν is indefinitely decreased, $\mathrm{N}_1=\mathrm{N}_1'$, with other similar equations. On Green's supposition that $\mathrm{A}=\mathrm{A}_1$, $\mathrm{B}=\mathrm{B}_1$, these conditions for Case I. (vibrations normal to the plane of incidence) lead to

$$\left.\begin{aligned} w&=w_1,\\ \frac{dw}{dx}&=\frac{dw_1}{dx};\end{aligned}\right\} \qquad (20)$$

and for Case II. (vibrations in the plane of incidence) to

$$\left.\begin{aligned} u&=u_1, & v&=v_1,\\ \frac{du}{dx}&=\frac{du_1}{dx}, & \frac{dv}{dx}&=\frac{dv_1}{dx},\end{aligned}\right\} \qquad (21)$$

which are Cauchy's conditions. The difference between the two theories lies in their treatment of the waves of longitudinal displacement.

[1] See p. 189.

According to both Green and Cauchy they depend on a function ϕ, where

$$\phi = \phi_0 e^{\iota(a'x + by + ct)} \quad . \quad . \quad . \quad . \quad (22)$$

And in both theories

$$a'^2 + b^2 = \frac{c^2\rho}{A} \quad . \quad . \quad . \quad . \quad . \quad (23)$$

Green puts A/ρ very large, so that $a'^2+b^2=0$, and

$$\phi = e^{\pm bx}\{K \sin(by + ct) + L \cos(by + ct)\} \quad . \quad . \quad (24)$$

while Cauchy, without any dynamical justification, writes $A/\rho = -c^2/k^2$, k being a large quantity, so that A is a small negative quantity. Hence $a'^2+b^2= -k^2$.

The assumption of a negative value for A leads to the conclusion that the modulus of compression is negative—that is, that the medium is such that pressure causes it to expand and tension to contract, and this alone is fatal to the theory.

§ 5. We come, then, to the conclusion that the phenomena of reflexion and refraction cannot be explained, any more than the phenomena of double refraction, on a purely elastic solid theory involving a sudden change of properties on crossing the interface. Green's theory is the only possible consistent one, and it, in its original form, leads to results differing from experiment.

Part II.—Modern Developments of the Elastic Solid Theory.

We now come to the consideration of rather more modern investigation on this subject. The limits of space will confine us to the theoretical work which has been done. The great experimental researches of Fizeau, Jamin, Quincke, Cornu, and others, will only be occasionally referred to. A complete account of these must be left for some future time.

Chapter I.—General Properties of the Ether on the Elastic Solid Theory.

The elastic solid theory of the propagation of light and double refraction has been discussed in various papers by Haughton, Lamé, St. Venant, Boussinesq, Von Lang, Sarrau, Lorenz, Rankine, Lord Rayleigh, Kirchhoff, and others.

§ 1. Haughton considered the problem of the general equations of an elastic solid in a paper read before the Irish Academy in 1846, in which he adopts Cauchy's views as to the constitution of the medium. These views are modified in a second paper,[1] read in 1849, in which the general equations are formed, and the correct expression found for the potential energy.

In this paper Haughton shows how to calculate the strain in any direction produced by a given elongation in the same direction. This strain is proved to be inversely proportional to the fourth power of the radius of a certain surface, called by Rankine the tasimonic surface. A form is found for the equation to the surface of wave slowness, which is said to reduce to MacCullagh's if the vibrations be strictly transversal; but, in making the reduction, the dilatation θ is equated to zero, its co-

[1] Haughton, 'On a Classification of Elastic Media and the Law of the Propagation of Plane Waves through them,' *Irish Trans.* vol. xxii. p. 97.

efficient remaining a finite quantity, and in consequence the results are erroneous.

§ 2. Lamé is the author of numerous papers, in the 'Comptes Rendus' and elsewhere, on the propagation of waves through an elastic medium, and his results are summed up in his 'Leçons sur l'Elasticité.' [1] The general form of the equations for the strains are shown to contain twelve constants, which become six if the dilatations be equated to zero, and three when planes of symmetry are taken for the co-ordinate planes. The equations of motion finally obtained may be written

$$\frac{d^2u}{dt^2}=c^2\frac{d}{dy}\left(\frac{du}{dy}-\frac{dv}{dx}\right)-b^2\frac{d}{dz}\left(\frac{dw}{dx}-\frac{du}{dz}\right) \quad . \quad . \quad (1)$$

etc., which agree with MacCullagh's and with Green's if we omit the terms involving the dilatation. The arguments to be advanced against the theory are identical, then, with those which Professor Stokes has urged against MacCullagh's.

§ 3. St. Venant has written many most important papers on the subject of elasticity. He still adheres to Cauchy's theory and the form of the equations of an elastic solid deduced from the hypothesis of direct action between the molecules of the medium, and in his last great work on the subject, the annotated French edition of Clebsch's 'Elasticity,' states his reasons for so doing in §§ 11, 16. However, in the work he employs Green's expression for the energy, with the twenty-one coefficients—'Vu la controverse actuelle où la majorité des avis est contraire au nôtre.'

§ 4. In a paper printed in 1863 [2] he criticises Green's theory of double refraction, arguing that Green's conditions for the tranversality of the vibrations lead to isotropy. This conclusion is frequently repeated in St. Venant's [3] papers, and it will therefore be well to investigate the point somewhat closely.

Let us suppose that we have a simple elongation ϵ in a direction l_1, m_1, n_1, in a medium fulfilling Green's conditions. Let $l_2, m_2, n_2, l_3, m_3, n_3$ be the direction cosines of two lines at right angles in a plane normal to l_1, m_1, n_1, and let us investigate the stresses $N_1', N_2', N_3', T_1', T_2', T_3'$ on the faces of an element normal to these directions. Then St. Venant's argument rests on the fact that N_1' is independent of the direction of the elongation, while T_2' and T_3' vanish, and that this would be the case in an isotropic medium. This last statement is of course true, but on Green's theory N_2', N_3' do depend on the direction, which they would not do in an isotropic medium, and T_1' has a finite value, while for an isotropic medium it would vanish.

The values for the stresses may be shown to be—

$$\left.\begin{aligned}
N_1' &= \mu\epsilon \\
N_2' &= \{\mu-2(Ll_3^2+Mm_3^2+Nn_3^2)\}\,\epsilon \\
N_3' &= \{\mu-2(Ll_2^2+Mm_2^2+Nn_2^2)\}\,\epsilon \\
T_1' &= 2\,\{Ll_2l_3+Mm_2m_3+Nn_2n_3\}\,\epsilon \\
T_2' &= T_3'=0
\end{aligned}\right\} \quad . \quad . \quad (2)$$

[1] Lamé, *Leçons sur l'Elasticité.* Paris: Gauthier Villars, 1866.

[2] St. Venant, 'Sur la distribution des élasticités autour de chaque point d'un solide,' *Liouville's Journal*, S. ii. t. viii. p. 257.

[3] See especially De St. Venant, 'Théorie des ondes lumineuses,' *Ann. de Chim.* S. iv. p. 22.

For an isotropic solid we should have $N_2' = N_3' = (\mu - 2L)\epsilon$ and $T_1' = 0$. Thus Green's medium in which the propagation of transverse waves is possible has properties which distinguish it from an isotropic solid, for a simple elongation produces on any plane parallel to the direction of the elongation a normal stress which depends on the position of the plane, while it also produces shearing stress about an axis parallel to the direction of the elongation; and although the theory does not explain double refraction satisfactorily, yet it is not open to De St. Venant's criticisms on this point.

§ 5 In the same paper St. Venant proposes a modification of Cauchy's theory which leads to Fresnel's wave surface without any more conditions than are required by Green; for, putting in Green's expression,

$$Al^2 + Bm^2 + Cn^2 = X \quad . \quad . \quad . \quad . \quad (3)$$

l, m, n being the direction cosines of the wave normal, the equation to determine the velocity becomes—

$$\begin{aligned}&\{\rho V^2 - X - Gl^2 - Hm^2 - In^2\}\left[(\rho V^2 - X)^2 - (\rho V^2 - X)\right.\\ &\qquad\left.\{(M+N)l^2 + (N+L)m^2 + (L+M)n^2\} + MNl^2 + NLm^2 + LMn^2\right]\\ &\quad - \{(H-L)(I-L) - (L+P)^2\}\ \{Gl^2 + Nm^2 + Mn^2 + X - \rho V^2\}m^2n^2\\ &\quad - \{(I-M)(G-M) - (M+Q)^2\}\ \{Nl^2 + Hm^2 + Ln^2 + X - \rho V^2\}n^2l^2\\ &\quad - \{(G-N)(H-N) - (N+R)^2\}\ \{Ml^2 + Lm^2 + In^2 + X - \rho V^2\}l^2m^2\\ &\quad + \{(G-M)(H-N)(I-L) + (G-N)(H-L)(I-M)\\ &\quad - 2(L+P)(M+Q)(N+R)\}l^2m^2n^2 = 0 \quad . \quad . \quad . \quad . \quad . \quad (4)\end{aligned}$$

And this will reduce to Fresnel's surface if $A = B = C$; that is, if the equilibrium stresses are equal, and the four conditions

$$\left.\begin{aligned}&(H-L)(I-L) = (L+P)^2\\ &(I-M)(G-M) = (M+Q)^2\\ &(G-N)(H-N) = (N+R)^2\\ &(G-M)(H-N)(I-L) + (G-N)(H-L)(I-M)\\ &\qquad\qquad - 2(L+P)(M+Q)(N+R) = 0\end{aligned}\right\} \quad . \quad (5)$$

are satisfied.

These equations include those of Green's first theory, and are approximately those which arise from what St. Venant calls an ellipsoidal distribution of elasticities. Under certain circumstances the tasinomic surface—which, it will be remembered, gives the tension in any direction produced by a simple elongation in that direction—reduces to an ellipsoid, and then the distribution of elastic constants is named by St. Venant ellipsoidal. This distribution is produced when an isotropic medium is unequally strained in three perpendicular directions. The theory is interesting, and important as showing that Fresnel's wave surface can be deduced from the general elastic solid theory on other assumptions as regards the constants than those given by Green, and that the vibrations in this case are not necessarily in the wave front. There will, however, in this case be a quasi-normal wave, the velocity of which is given by the equation

$$\rho V^2 - X - Gl^2 - Hm^2 - In^2 = 0;$$

and if Green's arguments as to the relative magnitude of the constants be still supposed to hold, the quasi-normal wave will disappear, and the vibrations will be very nearly indeed transversal. The theory, however, interesting as it is, does not enable us to overcome the difficulty of reconciling the theories of double refraction and reflexion so long as we adopt the view of Fresnel and Green, that the latter depends on difference of density, not of rigidity, in the two media. It is also open to the objection that if the medium be incompressible the displacements must be in the wave front, and we must get in this case Green's conditions, not the above; while if the medium be not incompressible an appreciable amount of energy must exist in the form of longitudinal vibrations.

§ 6. The question of the propagation of waves through an isotropic medium, which is rendered anisotropic by the production of three elongations, a, b, c, in three rectangular directions, has been studied by Boussinesq.[1] The elastic constants are taken to be linear functions of these permanent strains, and the number of constants involved in their expression is reduced from the considerations involved in the symmetry of the medium and the principle of the conservation of energy.

The equations of motion may be written

$$\left.\begin{aligned}\frac{d^2u}{dt^2} &= (\lambda+\lambda' a)\frac{d\theta}{dx} + (\mu+\rho a)\nabla^2 u \\ &+\sigma\left\{a\frac{d^2u}{dx^2}+b\frac{d^2u}{dy^2}+c\frac{d^2u}{dz^2}\right\} \\ &+\nu\frac{d}{dx}\left\{a\frac{du}{dx}+b\frac{dv}{dy}+c\frac{dw}{dz}\right\}\end{aligned}\right\} \quad . \quad . \quad . \quad (6)$$

with the condition implied by the principle of the conservation of energy that $\lambda'=\nu$, while if the normal stresses in the equilibrium condition vanish $\sigma=\rho$. These may be deduced from Green's equations by putting

$$\left.\begin{aligned}A=(\sigma-\rho)a,\quad B=(\sigma-\rho)b,\quad C=(\sigma-\rho)c,\\ G=\lambda+\mu+2(\rho+\nu)a,\\ L=\mu+\rho(b+c),\\ P=\lambda-\mu+(\nu-\rho)(b+c),\end{aligned}\right\} \quad . \quad . \quad (7)$$

with similar expressions for the other constants. λ and μ are the two elastic constants of the unstrained medium in the form in which they are written by Lamé, $\sqrt{\lambda}$ and $\sqrt{(\lambda+\mu)}$ being the velocities of transverse and normal waves respectively, the density being taken as unity.

It is thus shown that on the assumption that a, b, c are small quantities, such that their squares and products may be neglected, Fresnel's wave surface is given if either $\sigma=0$ or $\sigma=\rho$. In fact, the condition $\sigma=0$ leads to Fresnel's surface without any assumption as to the value of a, b, c, for then the theory becomes identical with Green's second theory; while if $\sigma=\rho$ we have either St. Venant's ellipsoidal condition or his suggested modification of Cauchy, for to this degree of approximation the two theories are identical.

[1] Boussinesq, *Liouville's Journal*, S. ii. t. viii.

We may conclude, then, that Fresnel's laws as to double refraction would hold in a medium strained in the manner Boussinesq considers, but the theory as a whole is liable to the same criticisms as have been made to Green's. Boussinesq is the author of another and different theory, which we shall consider later, and which gives a better explanation of the phenomena.

§ 7. This same problem has been dealt with by Professor C. Niven,[1] who has arrived at similar results without introducing considerations based on molecular reactions.

§ 8. The problem of double refraction has been treated in a different manner by M. Sarrau, following up the suggestions of Cauchy as to the nature of the ether in a crystal, and his theory is developed in two papers in 'Liouville's Journal.' In these papers[2] the density of the ether in a transparent medium is supposed to vary in a periodic manner from point to point. The ether is arranged in concentric shells of variable density round each matter molecule, and its density, variable round each matter molecule, is the same at any one of a series of points situated similarly with regard to the matter molecules. The ether is periodically homogeneous, and the coefficients which occur in the elasticity equations are no longer constant, but are periodic functions of the co-ordinates of the point whose displacement is being considered; from these equations are deduced a series of others with constant coefficients, containing the average displacements of the ether in an element of volume. It is to these average displacements that optical effects are supposed to be due.

Cauchy[3] has indicated the path to be followed in deducing these auxiliary equations from the fundamental forms, and M. Sarrau arrives at the following conclusion.

If the fundamental equations be represented by

$$\left.\begin{aligned} \frac{d^2u}{dt^2} &= \mathrm{F}\left(\frac{d}{dx'}\ \frac{d}{dy'}\ \frac{d}{dz'}\ u_1 v_1 w_1\right) \\ \frac{d^2v}{dt^2} &= \mathrm{G}\left(\ .\quad .\quad .\quad .\ \right) \\ \frac{d^2w}{dt^2} &= \mathrm{H}\left(\ .\quad .\quad .\quad .\ \right) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Where F, G, H are functions with periodic coefficients of u, v, w and their differential coefficients, then the auxiliary equations will be—

$$\left.\begin{aligned} \frac{d^2u}{dt^2} &= \mathrm{F}' + \mathrm{G}' + \mathrm{H}' \\ \frac{d^2v}{dt^2} &= \mathrm{F}'' + \mathrm{G}'' + \mathrm{H}'' \\ \frac{d^2w}{dt^2} &= \mathrm{F}''' + \mathrm{G}''' + \mathrm{H}''' \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

[1] C. Niven, *Quarterly Journal of Pure and Applied Mathematics*, No. 55, 1876.

[2] Sarrau, *C. R.* vol. lx. p. 1174. 'Sur la propagation et la polarisation de la lumière dans les cristaux,' *Liouville's Journal*, S. ii. t. xii. p. 1; t. xiii. p. 59.

[3] Cauchy, *Comptes Rendus*, t. xxx. p. 17.

F′, F″, F‴ being symbolic functions obtained by substituting integral functions of $\frac{d}{dx}, \frac{d}{dy}, \frac{d}{dz}$ for the periodic coefficients of F, and similarly for G′, H′.

The second memoir [1] is devoted to the consideration of the problem on the supposition that the ether in a crystal is isotropic as regards its elasticity, and that the variations in density are all which we have to consider. Again following Cauchy, and treating the ether as a system of attracting and repelling points, Sarrau arrives at the equations

$$\left.\frac{d^2u}{dt^2}=\mathrm{E}(\nabla^2)u+\mathrm{F}(\nabla^2)\frac{d\theta}{dx}\right\} \quad . \quad . \quad . \quad . \quad (10)$$

etc., where E and F are certain connected functions depending on the law of force, and θ the dilatation.

For free space—

$$\mathrm{E}(\nabla^2)=e\nabla^2,$$
$$\mathrm{F}(\nabla^2)=f,$$

e and f being constants.

For the ether in a crystal, omitting the consideration of dispersion, it is shown that it is probable that E and F have the same forms, only now e and f are periodic functions of the co-ordinates.

If we denote d/dx, d/dy, d/dz, d/dt by α, β, γ, σ, respectively, then the equations in the crystal become, in conformity with the general rule,

$$\sigma^2u=\nabla^2(\mathrm{F}_1u+\mathrm{F}_2v+\mathrm{F}_3w)+(f_1\alpha+f_2\beta+f_3\gamma)\theta,$$

etc., where F, G, H, etc., f, g, h, etc., denote now symbolic functions of α, β, γ.

These general equations are simplified by the consideration of the various kinds of symmetry possible, and it is shown that in the case of ordinary biaxial crystals they reduce to

$$\left.\begin{aligned}\frac{d^2u}{dt_2}&=f\nabla^2u+f_1\frac{d\theta}{dx}\\ \frac{d^2v}{dt^2}&=g\nabla^2v+g_1\frac{d\theta}{dy}\\ \frac{d^2w}{dt^2}&=h\nabla^2w+h_1\frac{d\theta}{dz}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (11)$$

It is further assumed that $f+f_1=g+g_1=h+h=0$. This, of course, is the condition that the velocity of the normal wave should be zero.

These equations are solved by putting $u=\mathrm{P}e^{k(lx+my+nz-\omega t)}$, etc., and lead to

$$\frac{\mathrm{P}}{\frac{fl}{\omega^2-f}}=\frac{\mathrm{Q}}{\frac{gm}{\omega^2-g}}=\frac{\mathrm{R}}{\frac{hn}{\omega^2-h}}=-(\mathrm{P}l+\mathrm{Q}m+\mathrm{R}n),$$

whence

$$\frac{l^2}{\omega^2-f}+\frac{m^2}{\omega^2-g}+\frac{n^2}{\omega^2-h}=0. \quad . \quad . \quad . \quad . \quad (12)$$

[1] *Liouville's Journal*, Ser. ii. t. xiii. p. 59.

Thus the wave surface is Fresnel's. The direction of vibration, the ray and the wave normal are shown to be in the same plane, but the direction of vibration is at right angles to the ray instead of to the wave normal.

The assumed conditions $f + f_1 = 0$, etc., form a serious objection to the theory as it stands, but on this point it is capable of modification. The vibrations, of course, are not strictly transversal within the crystal, but I am not aware of any experiments which prove that they must be so. Of course, if the medium be absolutely incompressible, the displacements must be in the wave front, and the theory fails; but the condition of stability and the evanescence of the longitudinal wave require merely that the incompressibility should be very great compared with the rigidity, without being absolutely infinite.

§ 9. M. Sarrau has considered the peculiar phenomena presented by quartz, and shows how on his theory the terms assumed by MacCullagh will arise.

For the crystalline symmetry of such a body, the equations are shown to take the form—

$$\left.\begin{aligned}\frac{d^2u}{dt^2}&=f\left(\nabla^2 u-\frac{d\theta}{dx}\right)+f_1\nabla^2\left(\frac{dw}{dy}-\frac{dv}{dz}\right)\\ \frac{d^2v}{dt^2}&=g\left(\nabla^2 v-\frac{d\theta}{dy}\right)+\nabla^2\left(g_1\frac{du}{dz}+g_2\frac{dw}{dx}\right)\\ \frac{d^2w}{dt^2}&=g\left(\nabla^2 w-\frac{d\theta}{dz}\right)+\nabla^2\left(g_1\frac{du}{dy}+g_2\frac{dv}{dx}\right)\end{aligned}\right\} \quad . \quad . \quad (13)$$

and it follows that two elliptically polarised waves can traverse the medium in any given direction.

The velocities of these waves are given by

$$\omega^2=g-\frac{1}{2}(g-f)\sin^2\theta \pm \frac{1}{2}\sqrt{\left\{(g-f)^2\sin^4\theta \right.}$$
$$\left. +\frac{16\pi^2}{\lambda^2}(g_2\cos^2\theta+f_1\sin^2\theta)\times(g_2\cos^2\theta-g_1\sin^2\theta)\right\} \quad . \quad (14)$$

f_1 and g_1 are two constants which are probably very small, and, in that case, the squares of the principal velocities at right angles to the axis are f and g, while the squares of the velocities parallel to the axis are given by

$$\omega^2=g\pm\frac{2\pi g_2}{\lambda}.$$

If ρ_1 represent the ratio of the axes of the ellipse in the ordinary wave, ρ_2 that in the extraordinary, then

$$\rho_1\rho_2=\frac{g_2\cos^2\theta-g_1\sin^2\theta}{g_2\cos^2\theta+f_1\sin^2\theta} \quad . \quad . \quad . \quad (15)$$

The major axis of the extraordinary ellipse is perpendicular to the principal plane, that of the ordinary ellipse is in the principal plane, while the two waves are polarised in opposite senses.

§ 10. De St. Venant[1] criticises the theory in the following points, ρ being the only periodic variable, the equations, he argues, should be treated as if the

[1] St. Venant, 'Sur les diverses manières de présenter la théorie des ondes lumineuses,' *Ann. de Chim.* (4), t. xxv. p. 335.

periodic coefficient was attached to the first term, $\rho \frac{d^2u}{dt^2}$, etc., and he states that the development of the equations $\rho \frac{d^2u}{dt_2} = \ldots$ leads to different results. Sarrau,[1] in reply, points out that this depends on the relative magnitudes of the quantities α, β, γ, σ^2, and the other parameters; on making the same suppositions in the two cases the results, he shows, are identical. One may, however, start from the general equations of an elastic solid with two coefficients, and, by supposing the coefficients to be periodic, arrive at the general equations already found.

M. de St. Venant finds a difficulty in explaining dispersion, for in an isotropic medium the periodicity of the coefficients vanishes. This may be true, and yet the equations contain differential coefficients above the second.

§ 11. The theory advanced by Von Lang[2] might perhaps more strictly be considered under the next section: 'Theories based on the mutual action between matter and the ether.' The theory is, however, so slight a modification of the ordinary elastic solid theory that it will be more convenient to deal with it now.

Von Lang supposes that the displacements which come into the ordinary elastic solid theory are displacements of the ether relative to the molecules of the matter. He assumes that the ratio of the matter displacement to that of the ether is in general a function of the direction, but that for three directions we may write

$$U = a^2u,\ V = b^2v,\ W = c^2w,$$

U, V, W being displacements of matter, u, v, w of ether.

He then forms the equations of motion, and, equating the velocity of the quasi-longitudinal wave to zero, arrives at Fresnel's wave surface. The theory cannot be regarded as having any real physical signification, for the elastic forces produced in the ether will depend on the real displacements of the ether particles, not on the displacements relatively to the matter, and the velocity of the normal wave cannot vanish, for if it does the medium becomes unstable.

§ 12. Von Lang[3] has also given a theory of circular polarisation, which consists in adding to the ordinary equations terms such as

$$\delta^2\left(\frac{dv}{dz} - \frac{dw}{dy}\right).$$

From this it follows that the velocity in a medium such as sugar is given by

$$\omega^2 = a^2 \pm \frac{\delta^2}{2\pi}\frac{V}{a}L,$$

L being the wave length in air; while in quartz

$$\omega^2 = a^2 - \frac{a^2 - c^2}{2}\sin^2\theta \pm \frac{1}{2}\sqrt{\left\{(a^2 - c^2)^2 \sin^4\theta + \frac{\delta^4\lambda^2}{\pi^2}\cos^4\theta\right\}} \quad . \quad (16)$$

[1] Sarrau, 'Observations relatives à l'analyse faite par M. de St. Venant,' *Ann. de Chim.* (4), t. xxvii. p. 266.
[2] Von Lang, 'Zur Theorie der Doppel-Brechung,' *Wied. Ann.* t. clix. p. 168.
[3] Von Lang, 'Zur Theorie der Circular-Polarisation,' *Pogg. Ann.* t. cxix. p. 74.

Von Lang holds that the experimental law connecting the rotation and the wave length is

$$\text{Rotation} = k + \frac{k'}{L^2} + \; . \; . \; . \; .$$

and this is given by the above expressions if

$$a^2 = m + \frac{n}{L^2} + \; . \; . \; . \; .$$

$$c^2 = m' + \frac{n'}{L^2} + \; . \; . \; . \; .$$

$$\delta^2 = rL + \frac{s}{L} + \; . \; . \; . \; .$$

No reason is given for assuming the form $\delta^2\left(\frac{dv}{dz} - \frac{dw}{dy}\right)$ rather than that selected by MacCullagh, $\delta^2\left(\frac{d^3v}{dz^3} - \frac{d^3w}{dy^3}\right)$, which leads to the correct relation between the rotation and the wave length without any violent supposition as to the form of δ^2, such as is made by Von Lang; and, though neither theory has any mechanical basis, this fact alone is sufficient to render MacCullagh's the more probable, while experiments on the size of the rings produced when convergent polarised light is transmitted through a plate of quartz cut at right angles to the axis agree rather better with MacCullagh's form than with Von Lang's.

§ 13. Another theory of double refraction was developed by Lord Rayleigh [1] in 1871. It had been suggested originally by Rankine,[2] and Stokes in his British Association Report referred to it, and showed that in its original form it was untenable. The theory is also given by Boussinesq in a paper in 'Liouville's Journal,' [3] which will be considered in full under the next section.

Lord Rayleigh points out the inconsistency already referred to between the theories of double refraction and reflexion given by both Green and Cauchy, while, as we shall see when considering the polarisation phenomena accompanying the reflexion, diffraction, and scattering of light, he believes that Neumann and MacCullagh, though consistent, were wrong throughout. He then remarks that the analogy of a solid moving in a fluid would suggest that the first effect of the matter molecules in a transparent body would be to alter the apparent density of the solid, and that conceivably this alteration might depend on the direction of vibration. He supposes that the statical properties of the ether are not altered by the presence of the matter, and the equations of motion may be written

$$\left.\begin{aligned} \rho_x \frac{d^2u}{dt^2} &= \frac{dp}{dx} + B\nabla^2 u \\ \rho_y \frac{d^2v}{dt^2} &= \frac{dp}{dy} + B\nabla^2 v \\ \rho_z \frac{d^2w}{dt^2} &= \frac{dp}{dz} + B\nabla^2 w \end{aligned}\right\} \quad . \quad . \quad . \quad (17)$$

where p is written for $A\delta$, δ being the dilatation.

[1] Hon. J. W. Strutt, 'On Double Refraction,' *Phil. Mag.* June 1871.
[2] Rankine, *Phil. Mag.* June, 1851. [3] See p. 215.

Lord Rayleigh further assumes the medium to be absolutely incompressible, so that δ is zero and A is infinitely large, p remaining finite; this, of course, leads to the fourth equation—

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=0 \quad . \quad . \quad . \quad . \quad (18)$$

And from these equations the equation to the surface of wave slowness is shown to be

$$\frac{l^2}{\frac{V^2}{a^2}-1}+\frac{m^2}{\frac{V^2}{b^2}-1}+\frac{n^2}{\frac{V^2}{c^2}-1}=0 \quad . \quad . \quad (19)$$

This, however, is not Fresnel's surface, and experiments of a very high[1] degree of accuracy have shown that the wave surface in a crystal is very approximately indeed Fresnel's surface, and of course this is fatal. But, as we shall see in the next section, according to all the theories yet proposed based on the mutual reaction between matter and ether, the first and most important effect of the matter is to alter the apparent density of the ether in the way here supposed. The mutual reaction, it can be shown, will introduce terms of the form $k\frac{d^2u}{dt^2}$ into the equations, and k may conceivably depend on the direction.

§ 14. Equations of motion practically the same as Lord Rayleigh's are given by Boussinesq, Lommel, Ketteler, and Voigt, and the question arises, Are these equations incompatible with Fresnel's wave surface? Lord Rayleigh has, of course, proved that they are if the equation

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=0$$

expresses an absolutely necessary condition; but it is not difficult to show that if, instead of the above equation, we put

$$\frac{1}{a^2}\frac{du}{dx}+\frac{1}{b^2}\frac{du}{dy}+\frac{1}{c^2}\frac{du}{dz}=0 \quad . \quad . \quad . \quad . \quad (20)$$

then the wave surface will be Fresnel's, the direction of vibration will be normal to the ray, and will be in the plane containing the ray, the wave normal, and an axis of the section of the ellipsoid $a^2x^2+b^2y^2+c^2z^2=1$ by the wave front, and while the velocity of propagation will be inversely proportional to the length of this axis.

Assuming equations of the same form as Lord Rayleigh's (17), we have to determine the pressural wave given by $p=p_0\epsilon^{i(lx+my+nz-Vt)}$ the equation

$$-\iota p_0=B\theta_0\left\{\lambda l\left(\frac{V^2}{a^2}-1\right)+\mu m\left(\frac{V^2}{b^2}-1\right)+\nu n\left(\frac{V^2}{c^2}-1\right)\right\},$$

where $$u=\lambda\theta_0\epsilon^{i(lx+my+nz-Vt)}, \text{ etc.,}$$

and this, on Lord Rayleigh's assumption of $l\lambda+m\mu+n\nu=0$, reduces to

$$p_0=\iota B\theta_0 V^2\left\{\frac{\lambda l}{a^2}+\frac{\mu m}{b^2}+\frac{\nu n}{c^2}\right\} \quad . \quad . \quad . \quad (21)$$

[1] See Stokes, *Proc. Roy. Soc.* vol. xx. p. 443; Abria, *Ann. de Chimie*; Glazebrook, *Phil. Trans.* Pt. I. 1879; Kohlrausch, *Wied. Ann.* t. vi. p. 86; t. vii. p. 427.

while, on the hypothesis suggested above, we should find

$$p_0 = -\iota B\theta_0\{\lambda l + \mu m + \nu n\} \quad . \quad . \quad . \quad . \quad (22)$$

The theory as here modified would, it appears to me, agree in its results with all the experimental facts; the main difficulty lies in the assumption of equations of the form $\frac{1}{a^2}\frac{d^2u}{dt} = \frac{1}{B}\frac{dp}{dx} + \nabla^2 u$ for the medium when it is not strictly incompressible. The value of p is generally $A\left(\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}\right)$, and the introduction of p is based on the supposition that $\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}$ is zero, and A infinite; it is questionable if the substitution ought to be made, except in this case.

§ 15. Kirchhoff's paper on double refraction [1] was read before the Royal Academy of Berlin, and is contained in their 'Transactions;' its more important part deals with the problem of reflexion and refraction. So far as the double refraction is concerned, it does not differ in any important points from Neumann's theory. The medium is supposed to be incompressible, so that $\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}$ vanishes, but the coefficient of this expression is treated as finite, and the terms involving it in the expression for the energy are omitted. The criticisms on Neumann's theory, contained in Professor Stokes's report, apply again here.

Chapter II.—Dispersion of Light.

In 1870 Ketteler [2] published a paper on dispersion, which forms the first of his important series on that subject. He commences with an account of Cauchy's theory and the various modifications which have been proposed.

§ 1. Redtenbacker [3] had considered the problem under the supposition that each matter molecule is surrounded by an ether shell, and obtained the formula

$$\frac{1}{\mu^2} = a + \frac{b}{\lambda^2} + c\lambda^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

λ being the wave length in the medium, and μ the refractive index.

§ 2. Christoffel,[4] discussing Cauchy's formula, already mentioned,[5] viz.

$$\frac{1}{\mu^2} = a + \frac{b}{\lambda^2} + \quad . \quad . \quad . \quad .$$

had shown that, while a and b may be considerable in value, the other constants decrease rapidly. This two-constant formula may be written—

$$\mu = \frac{\mu_0\sqrt{2}}{\sqrt{\left(1 + \frac{\lambda_0}{\lambda}\right)} + \sqrt{\left(1 - \frac{\lambda_0}{\lambda}\right)}} \quad . \quad . \quad . \quad (24)$$

[1] Kirchhoff, *Abhandl. der Königl. Akad. zu Berlin*, 1876.

[2] Ketteler, 'On the Influence of Ponderable Molecules on the Dispersion of Light, and the Signification of the Constants of the Dispersion Formulæ,' *Pogg. Ann.* t. cxl. p. 1.

[3] Redtenbacker, *Dynamiden-System*, Mannheim, 1857.

[4] Christoffel, *Pogg. Ann.* t. cxvii.

[5] See p. 165.

Thus μ_0 and λ_0 are the refractive index and wave length for the shortest waves transmitted, and $\mu_0\sqrt{2}$ the refractive index for the largest possible waves.

§ 3. The various theories are then compared with experiment, by Ketteler, and it is shown that the formula

$$\frac{1}{\mu^2} = \mathrm{K}\lambda^2 + \mathrm{A} + \frac{\mathrm{B}}{\lambda^2} + \frac{\mathrm{C}}{\lambda^4} \quad . \quad . \quad . \quad . \quad (25)$$

represents the results of the comparison most accurately. This formula was obtained by Briot, working on the same lines as Redtenbacker, but he supposes the coefficient K, which he shows depends on the direct action between matter and ether, to vanish. Van der Willigen [1] also called attention to the importance of the term in λ^2, but could not account for its existence. Ketteler, following Briot, then analyses the manner in which these various terms arise, and shows that the force on any vibrating ether particle may be written

$$\frac{4\pi^2}{\lambda^2}\left\{\text{Displacement of particle}\right\}$$
$$\times\left\{(g+h)(1-\mathrm{L}) - \frac{4\pi^2}{\lambda^2}\mathrm{M} + \frac{g_1+h_1}{4\pi^2}\lambda^2\right\}.$$

This, of course, gives

$$\frac{1}{\mu^2} = \mathrm{A} + \frac{\mathrm{B}}{\lambda^2} + \mathrm{K}\lambda^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

The term in $g+h$ arises from the mutual reactions of the ether particles, supposed to be uniformly distributed. If the action of the matter be simply to produce a periodic variation in the density of the ether, the terms in L and M are introduced, while the term involving g_1+h_1 comes from a direct force expressed by $mm_1rf_1(r)$ between the ether and matter particles m and m_1 respectively. If we put $rf_1(r) = \mu/r^n$, then the value of g_1+h_1 is $-\frac{1}{3}(n-2)\Sigma m_1\mu/r^{n+1}$.

Briot supposes that the term $\mathrm{K}\lambda^2$, to which this gives rise, is not required by the experimental results, and therefore puts $n=2$. Ketteler, however, shows that this term must be included.

Holtzmann and C. Neumann had already insisted on the importance of retaining in the equations terms to express this direct action, and Neumann gives as the expression in an isotropic medium for the force arising from a displacement u,

$$\mathrm{C}u + \mathrm{C}'\frac{d^2u}{dz^2} + \mathrm{C}''\frac{d^4u}{dz^4}.$$

But the theory of dispersion in its complete form requires that the motion of the matter particles should also be included. This is treated of in the next section of the Report.[2]

A problem closely connected with dispersion is the relation between the refractive index and the density of a medium. This has been dealt with experimentally by various physicists, notably by Gladstone and Dale in England, and Ketteler in Germany.

§ 4. L. Lorenz [3] has recently developed the theory of the transmission

[1] Van der Willigen, *Archives du Musée Teyler.* [2] See p. 213, etc.

[3] L. Lorenz, 'On the Refraction Constant,' *Wied. Ann.* t. xi.

of light through a medium consisting of a series of small spheres imbedded in the ether. The velocity of light in the interspaces is the same as in free space, and the wave length is supposed to be great compared with the intermolecular distances. It is assumed, then, that the disturbance u at any point may be written $u=(u_0+u_2)C+u_1S$, where the average values of u_1 and u_2 over the space containing some considerable number of molecules are zero, and C and S are written for the sine and cosine of $kt-lx-my-nz-\delta$. From this it follows that, if μ be the refractive index and d the density, $\frac{\mu^2-1}{\mu^2+2}$ is proportional to d.*

The paper is followed by one by Lorenz and K. Prytz, giving the results of an elaborate series of observations which show a close agreement between this expression and experiment.

Chapter III.—Aberration and Phenomena connected with the Motion of the Medium through which Light is being propagated.

§ 1. The aberration of light on the undulatory theory was accounted for by Fresnel[1] on the supposition that a moving body of refractive index μ carries with it a quantity of ether of density μ^2-1, the density in a vacuum being unity, while light is propagated through this ether, part of which is at rest and part moving with a velocity v (that of the body), as if the whole were moving with the velocity $(1-\mu^{-2})v$.

The experiments of Fizeau[2] on the displacement of the fringes of interference by a moving medium led to a result in close accordance with this theory.

§ 2. A more general and simpler proof than the one published by Fresnel of the fact that this leads to the ordinary laws of reflexion and refraction was given by Professor Stokes in 1846.[3]

In this paper Professor Stokes points out that the same result as to the velocity of light in the medium will be arrived at if we suppose the ether on entering the medium to be condensed, and on leaving it to be rarified, while the whole ether in the body travels with the velocity given above; for, if we take two planes, one outside the other inside the medium, each moving with the velocity v normal to itself, the quantity of ether which crosses the two planes per unit time will be the same, and hence, if V be the velocity of the ether in the medium, then we have, since the densities are 1 and μ^2 respectively,

$$v=\mu^2(v-V),$$

and hence

$$V=\frac{\mu^2-1}{\mu^2}v.$$

Moreover, this comes to the same thing as supposing the medium to be at rest, while the ether outside moves with a velocity v, and that inside with a velocity v/μ^2. The direction of a ray is shown to be that in which the same portion of a wave moves, moving relatively to the medium, and is found by drawing from a given point a line of length V/μ in a direction

* Compare this with a similar paper by H. A. Lorenz, p. 255.

[1] Fresnel, *Annales de Chimie*, t. ix. p. 57.

[2] Fizeau, *Annales de Chimie* (3), t. lvii. p. 385.

[3] Stokes, 'On Fresnel's Theory of the Aberration of Light,' *Phil. Mag.* vol. xxviii. p. 76; *Mathematical Papers*, vol. i. p. 141.

normal to the wave, and from the extremity of this line a second of length v/μ^2 in the direction of motion of the ether; the ray is the line joining the first point to the extremity of this second line. The velocity of the ether is resolved into its components perpendicular and parallel to the reflecting surface, and the effect of each component is considered; it is shown that rays are reflected and refracted according to the ordinary law of sines.

§ 3. But in a paper six months previously Professor Stokes[1] had considered the problem in a much more general manner. He supposes that the earth and planets carry with them a portion of the ether surrounding them, so that close to their surfaces the ether is relatively at rest, while the velocity alters as we recede from the surfaces until, at no great distance, it is at rest in space.

The direction in which a body is seen is normal to the waves which have reached the observer from the body, and the change in this apparent direction which arises from the motion of the ether is investigated.

The axis of z is taken in the direction of the normal to the undisturbed wave, and α, β, γ are the angles which the normal to the actual wave makes with the axes; u, v, w are the velocities of the ether at a point x, y, z at time t; V the velocity of light. The equation to the wave is

$$z = \mathrm{C} + \mathrm{V}t + \zeta,$$

ζ being a small function of x, y and t.

Then, by considering the displacement of the extremity of an element $\mathrm{V}\delta t$, drawn normal to the wave, it is shown that at time $t+\delta t$ the equation is

$$z = \mathrm{C} + \mathrm{V}t + \zeta + (w + \mathrm{V})\, dt,$$

and hence we see that

$$\frac{d\zeta}{dt} = w.$$

From this we find—

$$\alpha = \frac{\pi}{2} + \frac{1}{\mathrm{V}}\int \frac{dw}{dx}\, dz, \quad \beta = \frac{\pi}{2} + \frac{1}{\mathrm{V}}\int \frac{dw}{dy}\, dz.$$

If now

$$\frac{dw}{dx} = \frac{du}{dz}, \quad \frac{dw}{dy} = \frac{dv}{dz},$$

so that $udx + vdy + wdz$ is a complete differential, then

$$\alpha_2 - \alpha_1 = \frac{u_2 - u_1}{\mathrm{V}}, \quad \beta_2 - \beta_1 = \frac{v_2 - v_1}{\mathrm{V}}$$

and these equations, it is easily seen, imply the known law of aberration.

In an additional note it is shown that if α_1, β_1 be the inclinations of a ray at any time to the axes, then

$$\left.\begin{aligned} d\alpha_1 &= \left(\frac{du}{dz} - \frac{dw}{dx}\right) dt \\ d\beta_1 &= \left(\frac{dv}{dz} - \frac{dw}{dy}\right) dt \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (27)$$

[1] Stokes, 'On the Aberration of Light,' *Phil. Mag.* vol. xxvii. p. 9 (July, 1845); *Mathematical Papers*, vol. i. p. 134.

So that, if $udx + vdy + wdz$ be a complete differential, $d\alpha_1$ and $d\beta_1$ both vanish, and the path of the ray is a straight line.

Thus, if the motion of the ether produced by the passage of the transparent medium through it have a velocity potential, all the phenomena of aberration will be such as are actually observed. The important question as to whether such a motion is probable in the ether is discussed in another paper.[1]

§ 4. Professor Stokes's views on the constitution of the ether are given in his well-known paper on fluid friction.[2] He distinguishes there between the properties of rigidity and plasticity, pointing out that an elastic solid may under different external conditions become a viscous fluid, while the gradation between viscous and perfect fluids is quite regular. There seems, then, a probability that the property of rigidity will run to some extent through the whole series, becoming, in the case of fluids, masked by some other more important property. The mobility of a fluid is the limiting case of great plasticity; but even a perfect fluid may admit of a finite, though extremely small, amount of constraint of the nature of shearing stress before being relieved from its state of strain by its molecules assuming new positions of equilibrium. A consideration of the length of a wave in light motion—about ·00003 inches—renders it probable that 'the relative displacement of the ether particles may be so small as not to reach, or even come near, the greatest relative displacement which could exist without the molecules of the medium assuming new positions of equilibrium.'

These same views also tend to confirm the belief that for fluids, and among them the ether, the ratio of A to B (the elastic constants of the medium in Green's notation) will be extremely great.

We are led, then, to conclude that, in considering the motion set up in the ether by a moving body such as the earth, we may treat the ether as an incompressible fluid, while, on the other hand, when dealing with the extremely small disturbance produced by the passage of a light-wave the rigidity of the ether may come into consideration, and the equations required will be those of an elastic solid. In the first case any tangential forces which may arise, if the fluidity be not perfect, will depend on the relative velocities of the parts of the fluid; in the second case such tangential forces will depend on the relative displacements of those parts. In the paper in the 'Philosophical Magazine' for 1846 Professor Stokes shows that it is probable that a velocity potential will exist unless the action of the air on the ether be such as to prevent it, and, further, that it is improbable that the air will so act.

For suppose a sphere started from rest in such a medium, and then after a short interval stopped for a time, then started, and so on.

The initial motion will have a velocity potential, and if the fluid were perfect this would continue, so that reducing the sphere to rest would stop the motion everywhere. But the motion with the velocity potential is shown to be unstable, and hence there is left in the neighbourhood of the sphere a small outstanding disturbance. This is carried

[1] Stokes, 'On the Constitution of the Luminiferous Ether viewed with reference to the Phenomenon of the Aberration of Light,' *Phil. Mag.* vol. xxix. p. 6; *Math. and Phys. Papers*, i. p. 153.

[2] Stokes, 'On the Theories of the Internal Friction of Fluids in Motion, and the Equilibrium and Motion of Elastic Solids,' *Trans. Camb. Phil. Soc.* vol. viii. p. 287; *Math. and Phys. Papers*, i. p. 75.

off with the velocity of light, which is about 10,000 times as great as that of the earth, so that at the end of the second interval the ether near the sphere is at rest again and the same effect is repeated. It seems, therefore, probable that there will be a tendency to set up a motion in the ether not having a velocity potential, but that the beginnings of such motion will be propagated away into space at a very great rate, and that the actual motion will satisfy the condition that $udx+vdy+wdz$ is an exact differential.

In a subsequent paper Professor Stokes gives the solution of the equations of motion of a sphere moving in a viscous fluid, and then proves that when the fluid becomes perfect the motion becomes unstable, so that $udx+vdy+wdz$ is not a complete differential; but if the tangential force depends, not on the relative velocities, but on the relative displacements of the molecules—that is, if for the beginnings of the variation from irrotational motion we must consider the rigidity of the ether (*i.e.*, in our mathematics use the equations of an elastic solid)—then, as shown already, this nascent variation from irrotational motion will be propagated away by transverse vibrations, which, however, do not produce optical effects, either because they are too feeble or because they are discontinuous, or, if continuous, because their period falls outside that of the visible spectrum.

Or, to put it slightly differently, if the fluid has any very slight rigidity, a given arrangement of its parts is not necessarily one of equilibrium. Suppose, then, the fluid displaced from rest by the sudden motion of the solid, and that after a short interval the solid is stopped, the velocity of the fluid will be reduced everywhere to zero, but the resulting configuration will not necessarily be one of equilibrium, and the motion arising from this slight strain will be set up.

Thus, without making Fresnel's somewhat violent assumptions as to the relation between the ether within and without a transparent body, a perfectly reasonable and consistent account can be given of aberration depending only on the irrotational character of the motion induced by the moving body in the surrounding fluid. Unfortunately, as Professor Stokes points out, we have as yet no experiments competent to decide between the two, and he does not see how such experiments could be devised.

§ 5. Ketteler is the author of a long series of papers connected with the subject of aberration, which have appeared in Poggendorff's 'Annalen.' The last of these[1] contains a summary of the results of the whole. The problem of reflexion and refraction at a moving surface is considered, and it is shown that the intensities of the reflected and refracted rays will not be modified by the motion if the vibrations be at right angles to the plane of polarisation, as Fresnel supposed.

§ 6. The papers also deal with the problem of the emission of light from a moving source, and the principle first enunciated by Doppler,[2] in consequence of which it follows that if the source and receptacle approach each other in time t by a space equal to n times the wave length in the medium between the two, then the receptacle receives in that time n more vibrations than it would if the two were relatively at rest; and if this number be N, the apparent frequency is increased in the ratio $\mathrm{N}+n$

[1] Ketteler, 'Ueber den Einfluss der astronomischen Bewegungen auf die optisch n Erscheinungen,' Pt. VI., *Pogg. Ann.* t. cxlvii.

[2] Doppler, *Das farbige Licht der Doppel-Sterne.* 1842.

to N, or if V be the velocity of light, v that of the source towards the receptacle, in the ratio $V+v$ to V.

This principle has been considered by other writers, among them Petzval, Von Ettingshausen, Klinkerfuess,[1] Van der Willigen,[2] and Secchi,[3] and an interesting discussion of their work has been lately given by H. H. Turner, in a dissertation for a fellowship at Trinity College, Cambridge.

Chapter IV.—Reflexion and Refraction.

§ 1. The various theories of reflexion and refraction advanced by Fresnel, Green, MacCullagh, Neumann, and Cauchy have been discussed by several writers, and attempts have been made to reconcile them with the experiments of Jamin, Quincke, and others. Jamin was the first to show that by reflexion at most transparent media plane polarised light becomes elliptically polarised, and that this elliptic polarisation is most marked when the angle of incidence does not differ much from $\tan^{-1}\mu$. Moreover, for some substances for which the refractive index is greater than 1·4 the phase of the component in the plane of incidence is retarded relatively to that at right angles to the plane, while if the index be less than 1·4 the reverse is the case.

The original theories of Fresnel and MacCullagh do not in any way explain this phenomenon, and are therefore incomplete.

§ 2. Cornu[4] has discussed the application of Fresnel's theory to crystals, and has suggested a means of explaining the apparent discontinuity of the displacement normal to the surface to which that theory leads. The explanation—which Professor Stokes has been in the habit of giving, independently of Cornu, in his lectures at Cambridge—rests on the fact that the density of the ether is different in the two media. If, then, we take two planes in the two media parallel to the interface and at a small distance apart, the quantity of ether between the two planes remains the same; hence, if u, u' be the displacements normal to the planes, and ρ, ρ' the densities, the equation of continuity gives $\rho u = \rho' u'$, and this is the condition assumed by Cornu in his papers. This condition, combined with those of the continuity of the displacement parallel to the surface, is consistent with the equation expressing the conservation of energy.

The correctness of this condition depends on the view we take of the ether in the two contiguous media. If the two portions of ether be treated as two separate elastic solids in contact over a common surface, then over that surface the displacement must be the same in the two media; but the equality of the displacement normal to the surface cannot extend beyond a very small distance within the medium, and in the displacement is included that which comes from the pressural wave, as well as that which produces light. During the motion, of course, the bounding surface of the two media does not remain plane, but is a curved surface, the co-ordinates of any point on which at time t are u, $v+y$, $w+z$.

[1] Klinkerfuess, *Astronomische Nachrichten*, t. lxv. p. 17, t. lxvi. p. 337.

[2] Van der Willigen, *Archives du Musée Teyler*, t. iii. p. 306.

[3] Secchi, *C. R.* t. lxxxii. p. 761, t. lxxxiii. p. 117.

[4] Cornu, 'Recherches sur la réflexion crystalline,' *Ann. de Chim.* (4), t. xi. p. 283.

The condition of no dilatation holds throughout both media, and the stresses over the surface are the same in the two.

According to this view, a small portion of ether which belongs to one of the two media remains of unchanged density, and always forms part of the same medium.

We may, however, consider the question somewhat differently, and look upon the ether in the two media as continuous, but of different densities on the two sides of the interface. A portion of ether belonging to the first medium may cross the interface and become part of the second, and in so doing its density is changed. There will thus be a thin sheet of ether lying over the interface in which rapid periodic changes of density are occurring.

If, then, we consider the motion on the two sides of the sheet, we have for its determination the fact that the quantity of matter within the sheet is constant, and therefore that $\rho u = \rho' u'$, while the motion parallel to this sheet will ultimately be the same in the two media, and the energy in the reflected and refracted waves will be equal to that in the incident. But this condition $\rho u = \rho' u'$ does not hold within the sheet where the variations of density are taking place, and where the effects of the pressural wave are appreciable. The motions denoted by u and u' are light-motions, exclusive of those which give rise solely to the pressural wave. Moreover, it is supposed that this layer of variable density is so thin that the phase of the disturbance may be treated as the same over its two bounding surfaces. It is further assumed that the above are the only conditions which hold at the surface, and these can be satisfied without supposing any change of phase to arise from the reflexion. As a fact, there are other conditions involved in the equality of the stresses over the surface, and to satisfy these it is necessary to suppose that when the vibrations are in the plane of incidence the phases of the incident reflected and refracted waves differ even at the surface.

To assume Fresnel's conditions, as is done by Cornu, without change of phase is equivalent to supposing that this sheet of variable density is indefinitely thin when compared with the wave length of light.

Green himself considered the effect of supposing the change in refractive index to take place in a gradual manner, replacing the refracting surface by a regular series of layers, of indices μ_1, μ_2, etc., each of thickness τ; and proved that the effect of such a series would be to make the intensity of the reflected wave more nearly that given by Fresnel's tangent formula.

The effects of supposing the change of properties from one medium to the other to be gradual was discussed by L. Lorenz in the year 1860.

§ 3. In his first paper [1] he supposes that Fresnel's formulæ express the result of a sudden transition, and investigates how they must be modified if the transition be gradual. The variable sheet is divided into a series of layers, each of constant density. A ray reflected at one of the interior layers will on emergence be retarded relatively to the ray reflected at the surface. Let δ be the retardation of the ray reflected at a layer on which the angle of incidence is x, and let α, β be the angles of incidence and emergence, then the disturbances in the reflected ray are shown to be :—

[1] L. Lorenz, 'On the Reflexion of Light at the Bounding Surface of two Isotropic Media,' *Pogg. Ann.* t. cxi. p. 460.

(1) Light polarised in the plane of incidence—

$$R = A\frac{\sin(a-\beta)}{\sin(a+\beta)}\Big[\cos kt + \tan\triangle \sin kt\Big] \quad . \quad . \quad (28)$$

where

$$\tan\triangle = \frac{\sin a\cos a}{\sin^2 a - \sin^2\beta}\int_a^\beta\Big(\cos^2\beta\tan x - \sin^2\beta\cot x\Big)\frac{d\delta}{dx}dx \quad . \quad (29)$$

(2) Light polarised at right angles to the plane of incidence—

$$R' = -A'\frac{\tan(a-\beta)}{\tan(a+\beta)}\Big[\cos kt + \tan\triangle'\sin kt\Big] \quad . \quad (30)$$

where

$$\tan\triangle' = \frac{\sin 2a\sin 2\beta}{\sin^2 2a - \sin^2 2\beta}\int_a^\beta\Big[\frac{\sin 2x}{\sin 2\beta} - \frac{\sin 2\beta}{\sin 2x}\Big]\frac{d\delta}{dx}dx \quad . \quad (31)$$

Now $\frac{d\delta}{dx}$ is always small, hence $\triangle$ is small; but for $\sin 2a = \sin 2\beta$, or $\tan a = \mu$, $\tan\triangle'$ is infinite.

Jamin's results as to positive and negative reflexion are shown to follow, and if it be assumed that the density is approximately proportional to μ^2-1, the thickness of the variable sheet can be estimated, and is found to lie between $\frac{1}{10}$ and $\frac{1}{100}$ of the wave length.

In criticising this theory, Lord Rayleigh, in a paper we shall shortly consider, has pointed out that Fresnel's tangent formula does not express the result of sudden transition, and that Green's formula, which does, deviates from the truth on the other side. On the electro-magnetic theory, however, the tangent formula is strictly true, and Lorenz's investigations regain their interest.

Another objection which Lord Rayleigh has made to the supposition of gradual transition, however, may be a serious one. It is that there should be some indication of colour in the light reflected near the polarising angle, since it is to all intents and purposes a case of interference produced by a thin plate. It may, however, happen that the thickness of the plate is comparable with that of the black spot in Newton's rings, and so, though big enough to modify the quantity of light reflected, is too small to show colour. According to Newton, the thickness of the black spot in a soap film is about $\frac{1}{20}$ of a wave length, while Reinold and Rücker have recently determined it as $\frac{1}{50}$, and these fall within the limits required by Lorenz to explain the variations from Fresnel's tangent formula.

In another paper [1] the problem of reflexion at a surface across which the density varies gradually has been more fully considered by Lorenz, and the surface conditions on either side of the variable layer are deduced according to a strict elastic solid theory, and lead to similar conclusions.

§ 4. Cauchy gave the results of his theory of reflexion and refraction without the calculations which were supplied by Briot [2] in France, and Beer [3] and Eisenlohr [4] in Germany.

[1] L. Lorenz, *Pogg. Ann.* t. cxiv. p. 238.
[2] Briot, *Liouville's Journal*, t. xi. p. 305; t. xii. p. 185.
[3] Beer, *Pogg. Ann.* t. xci. and xcii.
[4] Eisenlohr, *Pogg. Ann.* t. civ. p. 346.

An account of the various theories is also given in papers by Lord Rayleigh,[1] with a careful criticism and comparison of them all.

In the first part of this paper Lord Rayleigh discusses fully the difference between the theories of Green and MacCullagh, and develops completely the consequences of the latter, taking into account the full effect of the pressural wave. This had been done first by Lorenz in the paper already referred to, and he showed that the results to which MacCullagh's theory leads are totally inconsistent with experiment.

Lord Rayleigh points out that the fundamental assumptions of Green and Fresnel amount to assuming an identity between the statical properties of the two media, while the dynamical properties depending on variation of density are different; while, moreover, as we have seen already, Cauchy's surface conditions, founded on the principle of the continuity of the displacements and their differential coefficients with reference to the normal, though erroneous if we suppose the rigidity of the ether different in the two media, become identical with Green's if we adopt his fundamental hypothesis. The real difference between Green and Cauchy lies in their respective treatments of the pressural waves.

The true surface conditions lead to the following results:—

Let ξ, η, ζ be the displacements, n the rigidity, m the second coefficient, such that $m+n$ is the A of Green's papers, and D the density, while $g^2 = (m+n)/\mathrm{D}$, $\gamma^2 = n/\mathrm{D}$ for the one medium.

Let $x=0$ be the bounding surface, and let the axis of z be parallel to the front of the waves. And suppose f, F, and f_1 to represent the incident reflected and refracted waves, while ϕ and ϕ' are the angles of incidence and refraction.

Then, for vibrations normal to the plane of incidence—

$$\frac{\mathrm{F}'}{f'} = \left.\frac{\dfrac{\tan\phi'}{\tan\phi} - \dfrac{n'}{n}}{\dfrac{\tan\phi'}{\tan\phi} + \dfrac{n'}{n}}\right\} \quad . \quad . \quad . \quad . \quad . \quad (32)$$

and this becomes:—

CASE I. $n = n'$ (Green, Fresnel, Cauchy)—

$$\frac{\mathrm{F}'}{f'} = \frac{\sin(\phi' - \phi)}{\sin(\phi' + \phi)} \quad . \quad . \quad . \quad . \quad . \quad (33)$$

CASE II. $\mathrm{D} = \mathrm{D}'$ (MacCullagh, Neumann)—

$$\frac{\mathrm{F}'}{f'} = \frac{\tan(\phi' - \phi)}{\tan(\phi' + \phi)} \quad . \quad . \quad . \quad . \quad . \quad (34)$$

Now, Jamin, Quincke, and others have shown that this latter formula is not strictly true, and hence at this point the evidence is already in favour of Fresnel's hypothesis.

Turning now to the case of the vibrations in the plane of incidence, put

$$\xi = \frac{d\Phi}{dx} + \frac{d\Psi}{dy},$$

$$\eta = \frac{d\Phi}{dy} - \frac{d\Psi}{dx}.$$

[1] J. W. Strutt, 'On the Reflexion of Light from Transparent Matter,' *Phil. Mag.* August, 1871; 'On the Reflexion and Refraction of Light by Intensely Opaque Matter,' *Phil. Mag.* May, 1872.

Then Ψ refers to the light wave and Φ to the pressural wave; let Ψ' refer to the incident wave, Ψ'' to the reflected, Ψ_1 to the refracted, so that

$$\Psi = \Psi' e^{i(ax+by+ct)} + \Psi'' e^{i(-ax+by+ct)},$$

etc. Then the surface conditions become in general, if we put

$$\Psi' + \Psi'' = X, \qquad \Psi' - \Psi'' = Y.$$

$$\left.\begin{aligned} i(\Phi + \Phi_1) &= \Psi_1 - X \\ b(\Phi - \Phi_1) &= aY - a_1\Psi_1 \end{aligned}\right\} \quad . \quad . \quad . \quad (35)$$

$$\begin{aligned}\Phi\{m(a'^2 + b^2) - 2nb^2\} &+ 2nabY \\ &= \Phi_1\{m'(a_1'^2 + b^2) - 2n'b^2\} + 2n'a_1b\Psi_1 \quad . \quad . \quad (36)\end{aligned}$$

$$\begin{aligned}n\{b^2\Psi_1 - a^2X &+ ib(aY - a_1\Psi_1)\} \\ &= n'\{b^2X - a_1{}^2\Psi_1 + ib(aY - a_1\Psi_1)\} \quad . \quad . \quad (37)\end{aligned}$$

MacCullagh, in his original work, neglects the pressural waves entirely, and puts $\Phi = \Phi_1 = 0$, deriving his result (Fresnel's sine formula) from equation (35). These results are inconsistent with (36) and (37), and therefore wrong. To obtain the correct solution we must remember that m is infinitely great, while $a'^2 + b^2$ is vanishingly small, and $m(a'^2+b^2) = Dc^2$. This is what has been done by Green, and applied by Lorenz and Lord Rayleigh to MacCullagh's theory.

[Cauchy puts $a'^2 + b^2 = -k^2$. We shall consider the consequences of this shortly.]

Hence (36) becomes

$$D\Phi - D'\Phi_1 = \frac{b^2}{c^2}(n - n')\left\{\frac{\Psi_1 - X}{i} - \frac{Ya + a_1\Psi_1}{b}\right\} \quad . \quad (38)$$

CASE I. $n = n'$ (Green).

Then

$$R' = R\frac{\tan(\phi - \phi')}{\tan(\phi + \phi')}\left\{\frac{1 + M^2\tan^2(\phi + \phi')}{1 + M^2\tan^2(\phi - \phi')}\right\}^{\frac{1}{2}} \quad . \quad . \quad (39)$$

R' and R being the amplitudes of the reflected and refracted waves, and M equal to $\dfrac{\mu^2 - 1}{\mu^2 + 1}$, while the difference of phase between the incident and refracted waves is e where

$$\cot e = \frac{1}{M}\cot(\phi - \phi') \quad . \quad . \quad . \quad . \quad (40)$$

while between the reflected and refracted waves it is e', where

$$\cot e' = \frac{1}{M}\cot(\phi + \phi') \quad . \quad . \quad . \quad . \quad (41)$$

CASE II. $D = D'$ (MacCullagh's corrected theory).

The equations are very complicated and lead, when the difference in the rigidities is very small, to two polarising angles of $22\frac{1}{2}°$ and $67\frac{1}{2}°$ respectively, results which are thus utterly at variance with experiments.

Cauchy's theory leads to results the same in form as Green's, if we substitute $-\epsilon\sin\phi$ for M, ϵ being a certain small constant.

The solution is contained in the above equations if we take

$$a'^2 + b^2 = -k^2, \qquad a_1'^2 + b^2 = -k_1{}^2,$$

and put

$$\frac{2\pi}{\lambda}\left(\frac{1}{k}-\frac{1}{k_1}\right)=-\epsilon \quad . \quad . \quad . \quad . \quad . \quad (42)$$

In Eisenlohr's account of Cauchy's work it is assumed at first that the normal waves travel with the same velocity as the transverse, and then the solution is modified by putting for $\lambda_{,,}$, λ'', the wave lengths of the normal waves, the values $-l_{,,}\sqrt{-1}$ and $-l''\sqrt{-1}$. This modifies $\phi_{,,}$ and ϕ'', the angles of refraction and reflexion of the normal waves, so that their sines become imaginary, while $\cos\phi_{,,}$ is real and negative, $\cos\phi''$ real and positive.

A difference of phase is thus produced, determined by the following equations:—

$$\tan e = p\tan(\phi-\phi'),$$

$$\tan e' = p\tan(\phi+\phi'),$$

where

$$p=\frac{m''-m_{,,}}{m''m_{,,}-1},$$

and

$$m_{,,}=\sqrt{\left(1+\frac{\lambda^2}{\lambda_{,,}^2\sin^2\phi}\right)},$$

$$m''=\sqrt{\left(1+\frac{\lambda^2}{\lambda''^2\sin^2\phi}\right)}.$$

Jamin's results show that p is very small; hence we may write

$$\frac{\lambda}{l_{,,}}=t+u,\ \frac{\lambda}{l''}=t-u,$$

where u is small, and then

$$p=\frac{2u\sin\phi}{t\sqrt{(t^2+\sin^2\phi)}} \quad . \quad . \quad . \quad . \quad (43)$$

Cauchy puts $p=\epsilon\sin\phi$, when ϵ is a small constant. Hence we must suppose that t is great compared with ϕ.

Lorenz and Lord Rayleigh have both pointed out the serious objection to be made to the theory in this form. The equation to determine Φ is $\frac{d^2\Phi}{dx^2}+\frac{d^2\Phi}{dy^2}=-\frac{k^2}{c^2}\frac{d^2\Phi}{dt^2}$, and the medium will be essentially unstable. Moreover, if k be a constant, ϵ varies inversely as λ, and chromatic effects near the polarising angle should be much more marked than they are.

I have, however, given an account of Eisenlohr's paper mainly because of another suggestion he makes, which renders it very nearly identical with Green's. He suggests that the normal or pressural waves may vanish 'by a sort of total reflexion, their velocity being very great compared with that of the transverse waves.' So that we have $\lambda_{,,}$ and λ'' very large instead of imaginary, and from this he finds

$$p=\frac{\lambda_{,,}^2-\lambda''^2}{\lambda_{,,}^2+\lambda''^2} \quad . \quad . \quad . \quad . \quad . \quad (44)$$

This vanishing by a sort of total reflexion is exactly Green's theory, for

if χ' be the angle of refraction for a normal wave produced by a transverse wave incident at an angle ϕ, then, with the notation of Lord Rayleigh's paper, $n \sin^2 \chi = m \sin^2 \phi$, and hence χ is imaginary unless ϕ is less than $\sin^{-1}(n/m)$. That is to say, if m be infinitely large, the effects of the pressural wave are entirely confined to the surface, and, indeed, for this total reflexion, if we may so call it, of the pressural wave to take place, it is practically not necessary for the ratio of n to m to be zero. If, for example, $n/m = 1/100$, there will be total reflexion if ϕ is greater than 0° 35′, and for so small an angle of incidence as this the component of the vibration normal to the surface on which the pressural wave depends would be too small to produce a measurable effect on the transmitted light.

If we put $\lambda_{,,}/\lambda'' = \mu_0$, then μ_0 is the refractive index of the medium for the normal vibrations, and we have for p

$$p = \frac{\mu_0{}^2 - 1}{\mu_0{}^2 + 1} \quad . \quad . \quad . \quad . \quad . \quad (45)$$

Now, it was shown, first by Haughton,[1] and then by Kurz, that the expressions (39–41) agree with experiment very closely if M or p be treated as a constant to be determined by experiment, and if we suppose p to have the form just given, then for sulphuret of arsenic, for which $\mu = 2{\cdot}454$, according to Jamin, $\mu_0 = 1{\cdot}083$. Green, going further into the mechanism of the motion, has shown, however, that on a strict elastic solid theory we must have $\lambda_{,,}/\lambda'' = \lambda/\lambda'$ and $\mu_0 = \mu$. The last conclusion Eisenlohr calls 'durchaus unhaltbar,' and in this he is right if he means that it does not agree with experiment, but wrong if he means that there is a flaw in Green's theory. The suggestion that μ and μ_0 may be different is due to Haughton,[2] but the reasons he has assigned for it have been shown by Eisenlohr to be invalid. Lord Rayleigh has suggested others which have great weight, and the importance of which will be more clearly seen when we come to consider some recent theories based on the mutual reaction between matter and the ether. The large quantities m and m' are, in Lord Rayleigh's paper, eliminated from the equations by means of the relations

$$m(a'^2 + b^2) \ = \mathrm{D}c^2,$$
$$m'(a_1{}'^2 + b^2) = \mathrm{D}'c^2,$$

D and D′ being the densities of the ether in the two media.

Now, in the pressural wave we are only concerned with a layer of ether close to the bounding surface, and Lord Rayleigh's suggestion is that, although the transverse vibrations are affected nearly in the same way as if the transition were instantaneous, it may not be so for the surface waves, and that therefore we may put $\mathrm{D}/\mathrm{D}' = \mu_0{}^2$ where μ_0 is less than μ. There are, I think, even stronger reasons for supposing μ_0 and μ to be different to be derived from the theory I have already referred to, which will be developed later.

Thus the papers of Lord Rayleigh, Lorenz, and Eisenlohr show, conclusively, that Neumann and MacCullagh's theory is inadmissible, and that Green's strict elastic solid theory, when slightly modified in a per-

[1] Haughton, *Phil. Mag.* (S. 4), vol. vi. p. 81; Kurz, *Pogg. Ann.* t. cviii.
[2] Haughton, *Phil. Mag.* (S. 4), vol. vi. p. 81; Eisenlohr, *Pogg. Ann.* t. civ p. 346.

fectly reasonable way, leads to results agreeing very closely with experiment, while Cauchy's method of treating the pressural wave requires an unstable condition in the ether.

In another paper Lord Rayleigh[1] considers the problem of reflexion at the confines of a medium of variable density. The incidence is supposed to be normal, and in, the particular problem solved completely, the density is supposed to vary as the inverse square of the distance from a fixed plane parallel to the surface. This variable medium extends between the two planes $x=x_1$, $x=x_2$, and the density is constant on the other sides of these planes, and it is shown that if the thickness of the variable layer is not very different from the difference in the wave lengths in the two, then, for the case in which the two media are air and glass, the reflexion will be excessively small.

§ 5. The paper by Kirchhoff[2] in which the problem of reflexion and refraction is considered has been already referred to. The theory there given is, in its results, nearly the same as those of Neumann and MacCullagh.

The ether is not treated strictly as incompressible, though it is supposed that only transverse waves are propagated, and therefore that the equation

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=0$$

is satisfied without the coefficient A becoming very large. These transverse waves falling on the interface of the two media would tend to set up longitudinal vibrations. Some surface action, however, is supposed to go on over the interface, the result of which is to quench these vibrations and the condition that this surface action should involve neither loss nor gain if energy is formed. This, with the three equations implied in the continuity of the displacement, makes four conditions from which the intensities and planes of polarisation of the reflected and refracted waves can be found.

The theory differs from MacCullagh's merely in recognising the possibility of the existence of the normal waves, and then accounting for their absence by means of some unknown surface action. It is not a strict elastic solid theory, nor does it attempt to explain of what nature the surface forces are which quench the normal waves. The formulæ to which it leads are identical with MacCullagh's,[3] and do not offer any explanation of the change of phase observed by Jamin. It can hardly be looked upon, therefore, as a satisfactory explanation of the phenomena, nor can we regard Kirchhoff's principle, as the fundamental hypothesis is called by various German[4] writers, as one which may replace the true surface conditions of an elastic solid.

Chapter V.—Metallic Reflexion.

§ 1. Various experimenters—and among them Brewster, MacCullagh, Briot, Airy, Neumann, De Senarmont, Jamin, Quincke, Wernicke, and Conroy—have investigated the optical effects produced by metallic re-

[1] Lord Rayleigh, *Proceedings of London Math. Soc.* vol. xi. No. 159.

[2] Kirchhoff, *Abh. der Königl. Akad. zu Berlin,* 1876

[3] See Glazebrook, 'On the Reflexion and Refraction of Light,' *Proc. Camb. Phil. Soc.* vol. iii. p. 329.

[4] See Ketteler, Voigt, etc.

flexions. They have shown that, in general, plane polarised light becomes elliptically polarised by such reflexion, and have measured the difference in phase between the components polarised in and perpendicular to the plane of incidence and the ratio of the intensities of these two vibrations.

MacCullagh [1] was the first to attempt to express the laws of this elliptic polarisation mathematically. He supposes that in the case in question the angle of refraction becomes imaginary, so that we have

$$\sin\phi' = \frac{\sin\phi}{m}\left(\cos\chi + i\sin\chi\right),$$

$$\cos\phi' = \frac{\cos\phi}{m'}\left(\cos\chi' + i\sin\chi'\right).$$

He then substitutes these expressions in the values given by Fresnel's theory for the amplitude of the reflected ray, which he shews may be written in the form $a+b\sqrt{-1}$.

Thus the intensity of this ray will be represented by a^2+b^2, and the difference of phase between the incident and reflected rays will depend on $\tan^{-1}b/a$; a and b are functions of m, m', χ, and χ', and these quantities are connected by the equation $\sin^2\phi'+\cos^2\phi'=1$, which leads to two conditions, giving m' and χ' in terms of m and χ.

The final formulæ are:—

(1) Light polarised in the plane of incidence.

$$I^2 = \frac{D^2 + \cos^2\phi - 2D\cos\phi\cos(\chi-\chi')}{D^2 + \cos^2\phi + 2D\cos\phi\cos(\chi-\chi')} \quad . \quad . \quad (46)$$

$$\tan 2\pi\frac{\delta}{\lambda} = \frac{2D\cos\phi\sin(\chi-\chi')}{\cos^2\phi - D^2} \quad . \quad . \quad . \quad (47)$$

(2) Light polarised perpendicular to the plane of incidence.

$$I'^2 = \frac{m^4\cos^2\phi + D^2 - 2Dm^2\cos\phi\cos(\chi+\chi')}{m^4\cos^2\phi + D^2 + 2Dm^2\cos\phi\cos(\chi+\chi')} \quad . \quad (48)$$

$$\tan 2\pi\frac{\delta'}{\lambda} = -\frac{2Dm^2\cos\phi\sin(\chi+\chi')}{m^4\cos^2\phi - D^2} \quad . \quad . \quad (49)$$

Where and

$$\left.\begin{aligned} D^4 &= m^4 + \sin^4\phi - 2m^2\sin^2\phi\cos 2\chi \\ D^2\sin 2(\chi-\chi') &= m^2\sin 2\chi \end{aligned}\right\} \quad . \quad . \quad (50)$$

These formulæ are simplified in the case of metals from the consideration of the fact that the proportion of light reflected at normal incidence is nearly unity. It follows from this that m is very large and χ' very small, so that we may put $\sin\chi'=0$, $\cos\chi'=1$ in the equations, and hence $m'=\cos\phi/\cos\phi'$,

And for Case I.—

$$\left.\begin{aligned} I^2 &= \frac{m^2 + m'^2 - 2mm'\cos\chi}{m^2 + m'^2 + 2mm'\cos\chi} \\ \tan\frac{2\pi\delta}{\lambda} &= \frac{2mm'\sin\chi}{m'^2 - m^2} \end{aligned}\right\} \quad . \quad . \quad . \quad (51)$$

[1] MacCullagh, *Proc. Irish Acad.* vol. i. pp. 2, 159; vol. ii. 375; *Trans. Irish Acad.* l xxviii. Pt. I.

and Case II.—

$$\left.\begin{aligned} I'^2 &= \frac{1 + m^2m'^2 - 2mm' \cos \chi}{1 + m^2m'^2 + 2mm' \cos \chi} \\ \tan 2\pi \frac{\delta'}{\lambda} &= - \frac{2mm' \sin \chi}{m^2m'^2 - 1} \end{aligned}\right\} \quad . \quad . \quad (52)$$

§ 2. Cauchy [1] has also given equations founded on his principle of continuity and the assumption of a peculiar form for the refracted ray which agree closely with those just established. His complete theory was never published by himself, and was first given by Eisenlohr. It has been further developed and criticised in some important points by Lord Rayleigh. Eisenlohr [2] takes for the displacement in a metal at a distance r from a source of light the expression $e^{\frac{2\pi\iota}{\lambda'}(\rho - r)}$, where λ' is a complex quantity connected with λ, the wave length in air, by the equation

$$\lambda = \lambda' \mathrm{R}e^{ia}.$$

Hence, using θ and θ' to denote the angles of incidence and refraction, we have

$$\sin \theta = \mathrm{R}e^{ia} \sin \theta' \quad . \quad . \quad . \quad . \quad (53)$$

The surface conditions of the continuity of the displacement and of the stresses become, as we have seen, identical with Cauchy's conditions of continuity of motion in the case in which the rigidity of the ether is the same in the two media, and the expressions for the intensity and change of phase for light polarised in the plane of incidence are most easily obtained by transforming Fresnel's sine formula, which is strictly true.

To effect the transformation put

$$\left.\begin{aligned} c^2 \cos 2u &= 1 - \frac{\cos 2a \sin^2 \theta}{\mathrm{R}^2} \\ c^2 \sin 2u &= \frac{\sin 2a \sin^2 \theta}{\mathrm{R}^2} \end{aligned}\right\} \quad . \quad . \quad . \quad (53)$$

Then the intensity in the reflected wave is

$$\mathrm{I}^2 = \tan \left(f - \tfrac{1}{4}\pi\right) \quad . \quad . \quad . \quad . \quad (54)$$

where

$$\cot f = \cos (u + a) \sin 2\tan^{-1}\left(\frac{\cos \theta}{\mathrm{R}c}\right);$$

while d, the change of phase, is given by

$$\tan d = \sin (a + u) \tan 2\tan^{-1}\left(\frac{\cos \theta}{\mathrm{R}c}\right) \quad . \quad . \quad (55)$$

These values agree with those given by MacCullagh if we put

$$\mathrm{R} = m, \quad a = - \chi,$$

[1] Cauchy, *C. R.* t. ii. p. 427; t. viii. pp. 553, 658; t. ix. p. 727; t. xxvi. p. 86. *Liouville's Journal*, t. vii. p. 338.

[2] Eisenlohr, *Pogg. Ann.* t. civ. p. 368.

and therefore
$$\left.\begin{array}{c} c \sec\theta = m', \quad u = \chi' \\ c\mathrm{R} = \mathrm{D} \end{array}\right\} \quad . \quad . \quad . \quad . \qquad (56)$$

For light polarised at right angles to the plane of incidence, Eisenlohr proceeds by transforming Fresnel's tangent formula in a similar manner, and finds
$$\mathrm{I}'^2 = \tan\left(g - \tfrac{1}{4}\pi\right) \quad . \quad . \quad . \quad . \quad . \qquad (57)$$
where
$$\cot g = \cos(a - u) \sin 2\tan^{-1}\left(\frac{c}{\mathrm{R}\cos\theta}\right) . \quad . \qquad (58)$$
and the change of phase is given by
$$\tan d' = \sin(a - u) \tan 2\tan^{-1}\frac{c}{\mathrm{R}\cos\theta} \quad . \quad . \qquad (59)$$

Hence in the general case the ratio of the amplitudes of the two reflected components is $\tan\beta$ where
$$\cos 2\beta = \cos(a + u) \sin 2\tan^{-1}\left(\frac{\sin^2\theta}{c\mathrm{R}\cos\theta}\right) \quad . \quad . \qquad (60)$$
and the difference of phase is given by
$$\tan(d' - d) = \sin(a + u) \tan 2\tan^{-1}\left(\frac{\sin^2\theta}{c\mathrm{R}\cos\theta}\right) \quad . \quad . \qquad (61)$$

These last equations depend on Fresnel's tangent formula, and this we know is not strictly true for transparent bodies. It is hardly probable, therefore, that the final equations for the difference of phase and the ratio of the amplitudes can be accepted as representing accurately the phenomena, and, in fact, Cauchy's theory as here developed is no great advance on MacCullagh's original expressions, with which it agrees throughout.

In this theory the expression for the disturbance in the metal is $e^{\frac{2\pi i}{\lambda}(\rho - r)\mathrm{R}(\cos a + \iota \sin a)}$, or, as we may write it,
$$\mathrm{A}e^{-\frac{2\pi}{\lambda} r\mathrm{R}\sin a} \sin \frac{2\pi}{\lambda}\left(r\mathrm{R}\cos a - ct\right).$$

Hence the velocity of wave propagation is $c/\mathrm{R}\cos a$, as against c in air, and $\mathrm{R}\cos a$ may be called the refractive index of the metal, while $\mathrm{R}\sin a$ measures the co-efficient of absorption. Now Jamin, Quincke, and others have measured the quantities $d - d'$ and β of the formulæ above, and from these Eisenlohr, in the paper already quoted, has calculated the values of R and a. He finds that for silver $a = 83°$. This result Lord Rayleigh has made the basis of a serious criticism on the whole theory.

Lord Rayleigh [1] endeavours to attach a physical meaning to the constants in these formulæ, and in so doing starts from equations taken to represent the motion in the medium.

Thus, for light polarised in the plane of incidence he assumes
$$\mathrm{D}_1 \frac{d^2\zeta}{dt^2} + h\frac{d\zeta}{dt} = n\left(\frac{d^2\zeta}{dx^2} + \frac{d^2\zeta}{dy^2}\right) . \quad . \quad . \qquad (62)$$

[1] Hon. J. W. Strutt, 'On the Reflexion and Refraction of Light by intensely Opaque Matter,' *Phil. Mag.* May, 1872.

with the solutions for the two media,

$$\left.\begin{aligned}\zeta &= \zeta' e^{\,i(ax+by+vt)} + \zeta'' e^{\,i(-ax+by+vt)}\\ \zeta_{\prime} &= \zeta_{\prime} e^{\,i(a_1x+by+vt)}\end{aligned}\right\} \quad . \quad . \quad . \qquad (63)$$

where

$$a = \frac{2\pi}{\lambda}\cos\theta, \qquad b = \frac{2\pi}{\lambda}\sin\theta, \qquad v = \frac{2\pi V}{\lambda},$$

θ being the angle of incidence. If we put $\gamma^2 = n/D$, $\gamma^2{}_1 = n/D_1$, we get from the differential equations—

$$\frac{a_1{}^2 + b^2}{a^2 + b^2} = \frac{\gamma^2}{\gamma_1{}^2}\left(1 - i\,\frac{h}{D_1 v}\right) = \mu^2, \text{ say} \quad . \quad . \quad . \qquad (64)$$

From this we get $\sin\theta' = \dfrac{1}{\mu}\sin\theta$, and hence μ is the quantity which we have denoted by $Re^{i\alpha}$.

Hence
$$R^2 e^{2i\alpha} = \frac{\gamma^2}{\gamma_1{}^2}\left(1 - i\frac{h}{D_1 v}\right). \quad . \quad . \quad . \qquad (65)$$

Thus $R^2 \cos 2\alpha$ is positive, and $R^2 \sin 2\alpha$ is negative, so that 2α lies between 0 and $-\frac{1}{2}\pi$ and $\tan 2\alpha = h/D_1 v$. Again, in the expression for the refracted wave we have $a_1 = \mu a$ when θ is zero, and hence we find that the real part of μ is positive, the imaginary part negative, so that finally α lies between 0 and $-\frac{1}{4}\pi$. This result is contradicted by Eisenlohr's value for silver, in accordance with which $\alpha = 83°$, from which it follows that the real part of μ^2 is negative, and this Lord Rayleigh says is tantamount to assuming the medium to be unstable. Eisenlohr [1] has replied to this that the objection is really one to the form of equation assumed by Lord Rayleigh, and that according to other theories (*e.g.* Helmholtz on anomalous dispersion [2]) real negative values of μ^2 are contemplated. With this reply we may in a sense agree. Lord Rayleigh's objection is a valid one, however, against the supposition that the peculiar effects of metallic reflexion may be explained by the introduction of terms such as $\dfrac{d^{2n+1}\zeta}{dt^{2n+1}}$ in the differential equations of an elastic solid ether, and forms an insuperable argument against the attempt to account for the effects on a purely elastic solid theory. When, however, we come to consider the theories depending on the mutual reaction of the ether and matter, we shall see that under certain circumstances the relation between the periods of the ether and matter molecules may be such as to give a negative value to μ^2, and thus render possible Eisenlohr's value for α.

The general value for a_1 for any angle of incidence may be shown to be given by

$$a_1 = \frac{2\pi}{\lambda} Rc\left\{\cos(u+\alpha) + \iota\sin(u+\alpha)\right\} \quad . \quad . \qquad (66)$$

[1] Eisenlohr, 'On the Reflexion of Light from Metals,' *Wied. Ann.* t. i.

[2] See p. 220.

c and u being defined by the equations of page 195, so that the expression for the refracted wave is

$$\zeta_{\prime} e^{-\frac{2\pi x}{\lambda} \mathrm{R}c \sin(u+a)} \sin \frac{2\pi}{\lambda}\left\{ \mathrm{R}cx \cos(u+a) + y \sin\theta + \mathrm{V}t \right\},$$

where, it must be remembered, x is measured in the negative direction.

Thus the coefficient of absorption is

$$\frac{2\pi}{\lambda} \mathrm{R}c \sin(u+a).$$

According to the experiments of Jamin and Quincke, the refractive index $\mathrm{R}\cos a$ for metal varies between $\frac{1}{4}$ and $\frac{1}{5}$.

§ 3. Wernicke,[1] however, deduced, from some experiments of his own, values lying between 3 and 4. Wernicke's experiments, however, were made by measuring the light transmitted at various angles of incidence by thin films of metal, and assuming that the light absorbed by a thickness d may be expressed by $bk^{d\sec\theta'}$, while the refractive index μ is given by $\sin\theta/\sin\theta'$. Eisenlohr, in the paper already quoted, shows that the quantity calculated by Wernicke is really $\{\mathrm{R}^2+\sin^2\theta\}^{\frac{1}{2}}$, and that his experiments confirm Jamin's and Quincke's.

In the second paper quoted Wernicke suggests, as the complete equations of motion, the form

$$\frac{d^2\xi}{dt^2}+\Sigma h\frac{d^m\xi}{dt^m}=\left(\mathrm{A}-\mathrm{B}\right)\frac{d\delta}{dx}+\mathrm{B}\nabla^2\xi+\Sigma k\frac{d^\mu}{dt^\mu}\left(\nabla^2\xi\right) \quad . \quad . \quad (67)$$

and other equations might be suggested which would give for the disturbance in the metal due to a point source expressions of the form

$$\mathrm{A}\epsilon^{-kr}\sin\frac{2\pi}{\lambda}\left(br-vt\right).$$

Chapter VI.—Diffraction and the Scattering of Light by Small Particles.

§ 1. The principle first enunciated by Huygens, and applied so triumphantly by Fresnel to the phenomena of diffraction, which consists in breaking up a wave front into elementary portions, calculating the effect of each in disturbing a distant point, and then finding the total disturbance at that point by simply summing the effects due to each element of the wave front, is a direct consequence of the fact that the disturbances and velocities are so small that their squares and higher powers may be neglected. The differential equations found for the motion are linear, and the complete solution is the simple sum of all the individual solutions. Again, it is fairly clear that the disturbance produced at any point by an element of a wave front will vary as the area of the element and the reciprocal of the distance between it and the point answered; but it is not so clear how the effect is related to the angles which the line joining the element and the point make with the wave normal and the direction of vibration respectively.

In Fresnel's theory of diffraction the consideration of effects produced

[1] Wernicke, 'On the Reflexion of Light from Metals,' *Pogg. Ann.* t. clix. and clx.

by the variation of these angles is omitted, and that, too, with perfect justice, for he is only concerned with the effects in the neighbourhood of the normal to the primary wave, and the dimensions of the diffracting aperture are small compared with the distance between it and the point at which the effects are considered, so that the change in either of these angles over the whole area of the diffracting area is small.

Again, it is clear that the effect will be a circular function of $r-vt$, r being the distance between the element and the point at which the disturbance is sought, and v the velocity of propagation; but the simple theory does not indicate the relation between the phase of this circular function and that of the function representing the disturbance in the original wave.

§ 2. Both these questions received their complete and final answer in the year 1849 from Professor Stokes.[1] We will quote a few words from the introduction to his paper: 'The object of the first part of the following paper is to determine on purely dynamical principles the law of disturbance in a secondary wave, and that not merely in the neighbourhood of the normal to the primary wave, but in all directions. The occurrence of the reciprocal of the radius in the coefficient, the acceleration of a quarter of an undulation in the phase, and the absolute value of the coefficient in the neighbourhood of the normal will thus appear as particular results of the general problem.'

The equations assumed for the motion are those of an elastic solid in the form given by Green—

$$\left.\begin{aligned} \frac{d^2\xi}{dt^2} &= b^2\nabla^2\xi + \left(a^2 - b^2\right)\frac{d\delta}{dx} \\ \text{etc., where} \qquad \delta &= \frac{d\xi}{dx} + \frac{d\eta}{dy} + \frac{d\zeta}{dz} \end{aligned}\right\} \quad . \quad . \quad . \quad (68)$$

In the preliminary analysis the important general theorem involved in the equations

$$\iint \frac{dV}{dn}ds = \iiint \left(\frac{d^2V}{dx^2} + \frac{d^2V}{dy^2} + \frac{d^2V}{dz^2}\right)dxdydz = 4\pi M \quad . \quad . \quad . \quad (69)$$

is proved.

It is then shown that the solution may be written

$$\xi = \xi_1 + \xi_2 \quad . \quad . \quad . \quad . \quad . \quad (70)$$

where

$$\left.\begin{aligned} \frac{d\xi_1}{dy} - \frac{d\eta_1}{dx} &= 0, \text{etc.,} \\ \frac{d\xi_1}{dx} + \frac{d\eta_1}{dy} + \frac{d\zeta_1}{dz} &= \delta \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (71)$$

and

$$\left.\begin{aligned} \frac{d\xi_2}{dy} - \frac{d\eta_2}{dx} &= \omega''' \\ \frac{d\xi_2}{dx} + \frac{d\eta_2}{dy} + \frac{d\zeta_2}{dz} &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (72)$$

[1] Stokes, 'On the Dynamical Theory of Diffraction,' *Trans. Camb. Phil. Soc.* vol. ix. p. 1; *Math. and Phys. Papers*, vol. ii. p. 243.

and that hence

$$\xi = -\frac{1}{4\pi}\iiint \frac{\delta}{r^2} \cos (rx) dv + \frac{1}{4\pi}\iiint \frac{1}{r^3}(y\omega''' - z\omega'') dv \quad . \quad (73)$$

It is proved that δ and ω', ω'', ω''' satisfy the equation

$$\left.\begin{aligned} \frac{d^2\delta}{dt^2} &= a^2 \nabla^2 \delta \\ \frac{d^2\omega}{dt^2} &= b^2 \nabla^2 \omega \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (74)$$

and hence, by Poisson's solution,

$$\delta = \frac{t}{4\pi}\iint \mathrm{F}(at)d\sigma + \frac{1}{4\pi}\frac{d}{dt}\left\{t\iint f(at)d\sigma\right\} \quad . \quad . \quad (75)$$

where f and F are the initial values of δ and $d\delta/dt$ respectively.

If, then, the values of δ and $d\delta/dt$, ω and $d\omega/dt$ be given initially everywhere, the last equation, with the similar one for ω, enable us to find δ and ω at any moment throughout the space considered, and then the equation (73) give us ξ, η, and ζ.

In solving the equations for δ, ω, it is clear that if we first find the part of the solution due to the initial velocity, the part due to the initial displacement may be obtained by substituting in the solution for the initial velocity the initial displacement, and then differentiating with regard to the time; and this proposition is proved generally for a system in which the forces depend only on the configuration of the system, and which is executing small vibrations about an equilibrium position.

The integrals are then modified by suitable transformations.

For ξ_1 we have $\xi_1 = \dfrac{d\psi}{dx}$, where $\psi = -\dfrac{1}{4\pi}\displaystyle\iiint \frac{\delta}{r}\, dv.$

Thus $-4\pi\psi$ is the potential of matter distributed throughout space with density δ, and finally it is shown that

$$\psi = -\frac{t}{4\pi}\iiint (u_0 x + v_0 y + w_0 z)\frac{dv}{r^3}(rat) \quad . \quad . \quad (76)$$

where u_0, v_0, w_0 are the initial values of the velocities at the point x', y', z', at which dv is an element of volume, r the distance between x', y', z' and x, y, z, the point at which ψ is to be found. From this ξ_1 can be found, and in a similar manner ξ_2. The terms ξ_1, η_1, ζ_1 arise from a wave of dilatation which is in general set up by any arbitrary displacement, and which travels through the medium with velocity a. If the initial disturbance be such that $\delta_0 = d\delta_0/dt = 0$ everywhere, then this wave will not be formed.

The terms ξ_2, η_2, ζ_2 arise from a wave of distortion which traverses the medium with velocity b. If a disturbance be produced at a point O, and last there for a time τ, then the motion at a point P, at a distance r from O, will not commence until after an interval t, where $t = r/a$, P will be disturbed by a wave of dilatation lasting for an interval τ; it will be disturbed by the wave of distortion after a time r/b, and this disturbance will last for an interval τ.

The general integral is then applied to two cases, which must be carefully distinguished from each other. In the first case, suppose that a periodic force acting parallel to a fixed direction acts throughout a given element of volume in the medium. Let the plane of xz contain the fixed direction, and let the axis of x make an angle α with it. Let D be the density, and T the volume of the element, and let $(\mathrm{DT})^{-1}f(t)dt$ be the velocity communicated to it in time dt.

Then

$$\left.\begin{aligned}
\xi &= \frac{\cos\alpha}{4\pi\mathrm{D}a^2r}f\left(t-\frac{r}{a}\right)+\frac{\cos\alpha}{2\pi\mathrm{D}r^3}\int_{\frac{r}{a}}^{\frac{r}{b}}t'f(t-t')dt \\
\eta &= 0 \\
\zeta &= \frac{\sin\alpha}{4\pi\mathrm{D}b^2r}f\left(t-\frac{r}{a}\right)-\frac{\sin\alpha}{2\pi\mathrm{D}r^3}\int_{\frac{r}{a}}^{\frac{r}{b}}t'f(t-t')dt
\end{aligned}\right\} \quad . \quad . \quad (77)$$

Now, we have seen that in the ether the ratio a/b is probably very large, hence the first term in ξ, on which the normal vibrations depend, is probably very small compared with the first term in ζ. The molecules of an incandescent body may be looked upon, at least very approximately, as centres of disturbing forces, and the above equations show us how it is that from such centres transverse vibrations only are propagated.

If the ether be absolutely incompressible, so that a/b is infinite, then longitudinal vibration would be impossible.

Suppose, now, the first term in ξ omitted, and put $f(t) = c \sin 2\pi bt/\lambda$, Then for the most important term we have—

$$\zeta = \frac{c\sin\alpha}{4\pi\mathrm{D}b^2r}\sin\frac{2\pi}{\lambda}\left(bt-r\right) \quad . \quad . \quad . \quad (78)$$

and the first term in ξ is of the order $\lambda/\pi r$ compared with the leading term in ζ. Hence, except at distances from the source which are comparable with the wave length, the terms in ξ may be neglected, and the motion is strictly transverse.

This solution applies to the case of an element of volume vibrating in any given manner and emitting light into the surrounding space. Everything is symmetrical around the direction of vibration of the element of volume. It does not apply, as has been supposed by some writers, to the problem of diffraction; for in this case we have a train of waves being propagated through an aperture, and producing disturbance in the medium beyond.

Let us suppose the aperture to be plane, and that plane waves are being propagated through it in the direction of its normal; take this for the axis of x, the plane of the aperture being $x = 0$, and the axis of z the direction of vibration. Let O_1 be a point in the aperture, and consider the disturbance propagated in a small interval of time τ, across an element $d\mathrm{S}$, at O_1. This disturbance occupies a film of thickness $b\tau$, and consists of a displacement $f(bt')$ and a velocity $bf'(bt')$. Thus, for a point O, at a distance r from O_1, and at a time t, given by $t = t' + r/b$, the initial disturbance is the above displacement and velocity extending over a volume $b\tau d\mathrm{S}$ about O; and if l, m, n are the direction

cosines of O_1O, measured from O_1, then the values of ξ, η, ζ depending on the initial velocity are—

$$\left.\begin{aligned} \xi' &= -\frac{lnds}{4\pi r} f'\left(bt-r\right) \\ \eta' &= -\frac{mnds}{4\pi r} f'\left(bt-r\right) \\ \zeta' &= \frac{(1-n^2)ds}{4\pi r} f'\left(bt-r\right) \end{aligned}\right\} \quad . \quad . \quad . \quad (79)$$

while the values depending on the initial displacement are—

$$\left.\begin{aligned} \xi'' &= -\frac{l^2nds}{4\pi r} f'\left(bt-r\right) \\ \eta'' &= -\frac{lmnds}{4\pi r} f'\left(bt-r\right) \\ \zeta'' &= \frac{l(1-n^2)ds}{4\pi r} f'\left(bt-r\right) \end{aligned}\right\} \quad . \quad . \quad . \quad (80)$$

From this it follows that the vibration at O, arising from that at O_1, lies in the plane through O_1O and the axis of z, and is perpendicular to the radius O_1O; and if ϕ be the angle between the axis of z and the line O_1O, θ that between O_1O and the wave normal, the value of this displacement is—

$$\zeta = \frac{dS}{4\pi r}\left(1 + \cos\theta\right) \sin\phi f'\left(bt-r\right) \quad . \quad . \quad (81)$$

Hence if $$f(bt) = c \sin\frac{2\pi}{\lambda} bt,$$

$$\zeta = \frac{cdS}{2\lambda r}\left(1 + \cos\theta\right) \sin\phi \cos\frac{2\pi}{\lambda}\left(bt-r\right) \quad . \quad . \quad (82)$$

and the total effect at O will be found by integrating this over the whole wave front.

We have thus found the complete expression for the law of disturbance in the secondary wave, and can see in what way it involves θ and ϕ, and how its phase is related to that of the disturbance over the primary wave.

The theory of diffraction given by Fresnel, and applied by him to points in the neighbourhood of the principal wave normal, is thus fully justified, since for such points θ is small, and $\cos\theta$ therefore approximately unity, while ϕ is nearly constant. The expression shows that an addition of a quarter period must be made to the phase; but this will not affect the form of the diffraction pattern obtained.

But the results of the investigation are of even more importance in their bearing on the relation between the position of the plane of polarisation and the direction of vibration of plane polarised light. For consider a ray diffracted in a direction making an angle θ with the incident wave normal, and let the plane containing the incident and diffracted ray be called the plane of diffraction, and let the directions of vibration

in the incident and diffracted rays make angles α_i, α_d with the normal to the plane of diffraction. Then the diffracted ray and the two directions of vibrations lie in the same plane, and the directions of vibrations are normal to the respective rays. Thus, if we form a spherical triangle by drawing lines from the centre of a sphere, parallel to the normal to the plane of diffraction and to the two directions of vibrations, since the direction of vibration in the diffracted wave is the projection on that wave of the direction of vibration in the incident wave, we have

$$\cos\theta = \tan\alpha_d \cot\alpha_i \quad . \quad . \quad . \quad . \quad (83)$$

Now, let ϖ and α be the azimuths of the planes of polarisation of the incident and diffracted light, measured from a plane normal to the plane of diffraction. Then, on Fresnel's assumption that the direction of vibration is normal to the plane of polarisation, we have

$$\varpi = \frac{\pi}{2} + \alpha_i, \qquad \alpha = \frac{\pi}{2} + \alpha_d,$$

and

$$\tan\alpha = \sec\theta \tan\varpi;$$

while on MacCullagh's hypothesis

$$\varpi = \alpha_i, \qquad \alpha = \alpha_d,$$

and

$$\tan\alpha = \cos\theta \tan\varpi \quad . \quad . \quad . \quad . \quad (84)$$

These two formulæ can be tested by experiment, and afford a means, therefore, of deciding between the two theories of reflexion, and of determining the question whether reflexion be due to a change of density or to a change of rigidity in the ether; for the values of α corresponding to a series of values of ϖ can be observed for any given angle of diffraction, and if the values of ϖ be taken at equidistant intervals, the values of α, and therefore the positions of the plane of polarisation of the diffracted light, will not be equidistant, but will on the first hypothesis be crowded towards the plane of diffraction, while on the second they will be crowded away from that plane.

Professor Stokes was the first to carry out a series of observations of this nature; he employed a grating ruled on glass at the rate of 1,300 lines to the inch, and the results of his experiments are decisive in favour of Fresnel's hypothesis. The experiments are troublesome, and the comparison of the results with theory is complicated by the fact that the refraction through the glass plate on which the grating is ruled also produces a change in the position of the plane of polarisation. The amount of this change is the same on the two theories, and tends to produce a crowding of the planes of polarisation away from the plane of diffraction, an effect opposite to that produced by diffraction on Fresnel's theory. Moreover, we may suppose that, when the ruled face of the grating is towards the incident light, either the diffraction takes place in air so that the wave enters the glass obliquely, or that the diffraction takes place in the glass after the light has entered the first surface normally, while when the ruled surface is away from the incident light the diffraction may take place in air after passing normally through the glass, or in the glass so that the light after passing normally through the first surface emerges obliquely.

In any case we shall have

$$\tan \alpha = m \tan \varpi \quad . \quad . \quad . \quad . \quad . \quad (85)$$

where m is a function of the angle of diffraction and the refractive index, which can be calculated on either of the above hypotheses.

The results were reduced by plotting from the experiments a curve with $\log m$ as ordinates and θ, the angle of diffraction, as abscissæ. The curves given by the two theories on either of the above assumptions as to the relation between diffraction and refraction were also drawn, and a comparison of the two results 'leaves no reasonable doubt that the experiments are decisive in favour of Fresnel's hypothesis, if the theory be considered as well founded.' And, moreover, the comparison shows us that we must suppose the diffraction to take place before the refraction. Thus, when the grooved face is towards the incident light we must suppose the wave to be broken up in the air and then to be obliquely refracted through the glass, while when the grooved face is away from the light the wave must be treated as if it were diffracted in the glass and then obliquely refracted out, and Professor Stokes shows that it is *à priori* more probable from physical reasons that this is what takes place.

§ 3. In the results of the experiments a certain amount of irregularity is produced by the want of symmetry of the grooves of the grating, and Holtzmann,[1] who in 1856 repeated Stokes's experiments, failed to obtain consistent results with glass gratings, and had recourse in consequence to a Schwerd's lamp-black grating; with this he obtained results more in accordance with the theory of Neumann and MacCullagh than with that of Fresnel.

Holtzmann thought that Stokes had neglected to consider the effect of the longitudinal waves, 'and to this neglect he attributes the error of Mr. Stokes;' and Eisenlohr,[2] who 'had not read the great paper of Prof. Stokes,' attributes to him the same neglect, and endeavours to give a theoretical account of the question from Cauchy's standpoint. Of course both these authors were quite wrong in their estimate of Stokes's work, and Lorenz[3] showed, from some decisive experiments of his own, that Holtzmann's results were due to an error of his method. Lorenz gave a fresh demonstration of Stokes's theorem, and arrived at the same results. Lorenz appears to consider his method as more general than that of Stokes, but this is due to a misconception on his part. The results of his experiments agree with Fresnel's theory.

§ 4. The matter has since been experimentally investigated by Quincke,[4] who showed that the method of forming the grooves on the grating was of the utmost importance, and whose experiments led to no decisive results, and more recently by Fröhlich.[5] Fröhlich investigated the polarisation of the light reflected from a glass grating, but did not compare his results with theory. A few experiments of the same kind were made by Stokes in 1852, but he also omitted the comparison with theory.

[1] Holtzmann, *Pogg. Ann.* t. xcix. p. 446.
[2] Eisenlohr, *Pogg. Ann.* t. civ. p. 337.
[3] L. Lorenz, *Pogg. Ann.* t. cxi. p. 315.
[4] Quincke, 'Experimentelle optische Untersuchungen,' *Pogg. Ann.* t. cxlix. p. 73.
[5] Fröhlich, *Wiedemann*, t. i.

Réthy [1] developed a theory which covers Fröhlich's experiments, and arrived at a formula with which they agree closely, but his fundamental principles are at fault.

In his solution Réthy adopts a method given by Kirchhoff to find the effects of a given source of light.

The equations to be solved are, if we neglect the terms involving dilatation,

$$\frac{d^2u}{dt^2}=\mathrm{V}^2\nabla^2u,$$

etc., with the condition

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=0.$$

Take

$$\Phi=\frac{\mathrm{A}}{r}\sin 2\pi\left\{\frac{r}{\lambda}-\frac{t}{\mathrm{T}}+\epsilon\right\} \quad . \quad . \quad . \quad (86)$$

Then Φ and its differential coefficients satisfy the equations of motion, and we require to find such solutions as will satisfy the equation of continuity.

Réthy takes as solutions—

I. $$u=\frac{d\Phi}{dy},\ v=-\frac{d\Phi}{dx},\ w=0 \quad . \quad . \quad . \quad . \quad (87)$$

and

II. $$u=-\frac{d^2\Phi}{dxdy},\ v=-\frac{d^2\Phi}{dydz},\ w=\frac{d^2\Phi}{dx^2}+\frac{d^2\Phi}{dy^2} \quad . \quad . \quad (88)$$

The distance r, of course, is measured from a point on the grating to the point at which the motion is being considered.

Now each of these expressions of course represents the solution due to some arbitrary motion set up somehow over the grating. In Case I. the motion is a periodic twist of each element about the axis of z, while in Case II. it is an oscillation parallel to that axis. But Réthy does not show how this motion is to be set up, nor whether it can represent the effect of a train of plane waves falling on the grating and there diffracted; and a little consideration shows that it cannot, for, according to the ordinary assumed properties of the ether, we cannot get the wave of twist only without linear displacement; the second solution corresponds to that due to the action of a periodic force at the origin generating a certain amount of momentum, and not to the complete effect of a train of waves. If we compare it with Stokes's solution, we see that it is that part which arises from the effects of the velocity propagated across the element, and omits the part due to the displacement. Stokes's solution applies to the case in which energy is being propagated by waves passing across the orifice into the medium beyond, and depends on the direction of motion of these main waves. Réthy's solution is that which arises from a centre of vibration situated on the surface, kept in motion by some external force and sending out waves in all directions into the medium. Still, we can arrive at a formula of the same nature as that given by Réthy, and which does agree with Fröhlich's experiments, by means of a simple extension of Stokes's principles. This consists in supposing that

[1] Réthy, *Wied. Ann.* t. xi. p. 504.

the incident waves set up vibrations over the surface parallel to a fixed direction, and that these vibrations lie in the same plane as the incident vibrations, while these vibrations set up others in the diffracted waves which lie in the same plane as those over the surface, and are everywhere normal to the diffracted rays. Then, if e_0 be the angle between the incident wave normal and the disturbance over the surface, ϕ_0 and ϕ the azimuths of the planes of polarisation on Fresnel's hypothesis measured from the plane of incidence in the incident and diffracted waves, and δ the angle of diffraction, it can be shown that[1]

$$\cos\phi_0 \tan\phi = \sin\delta \cot e_0 + \cos\delta \sin\phi_0 \quad . \quad . \quad (89)$$

This expression is given by Réthy, and agrees closely with the results of Fröhlich's experiments which were made with two gratings—the one of 19·76 lines to a millimetre, the other of 162 lines to a millimetre.

The value of e_0 depends on the angle of incidence when this vanishes, so that the vibrations in the incident wave are parallel to the surface $e_0 = 90°$, and the above formula becomes identical with Stokes's.

In comparing the two it must be remembered that the azimuths of the planes of polarisation are measured, in Stokes's expression, from the normal to the plane of incidence, while in Réthy's they are measured from the plane of incidence.

A careful series of experiments by Cornu[2] also lead to the conclusion that the vibrations are normal to the plane of polarisation. This conclusion coincides with that arrived at by Lord Rayleigh and Lorenz from considerations based on the phenomena of reflexion and refraction, and is further strengthened by the phenomena of polarisation produced when light is scattered by a series of small particles.

§ 5. Before considering this, reference must be made to a paper by Professor Rowland,[3] of Baltimore, on the subject. This paper will be more completely discussed when we come to the electro-magnetic theory, to which it more properly belongs. Professor Rowland, however, considers that he has discovered an error in Stokes's work, in that according to it 'when a wave is broken up at an orifice the rotation is left discontinuous by Stokes's solution.' It is not quite clear, however, how this criticism is intended to apply; for the rotation in the main wave is completely determined when the displacement is known. Now, Professor Stokes has shown that when the orifice is of finite size the aggregate disturbance at any point due to all the elements of the orifice, as found by his formula, is the same as if the wave had not been broken up. The rotation, therefore, as given by this formula is also the same.

Again, the rotation is propagated according to the same laws as the transverse disturbance, and hence the elementary rotation due to a given element of a wave propagated in a given direction is related to the direction and to the total rotation of the element in the same way as the elementary displacement propagated in that direction is related to the actual displacement.

Thus, if the displacements over the wave be

$$\xi = 0, \quad \eta = 0, \quad \zeta = c \sin\frac{2\pi}{\lambda}(bt - x),$$

[1] See Glazebrook, *Proc. Camb. Phil. Soc.* vol. v. p. 254. [2] Cornu, *C. R.*
[3] Rowland, 'On Spherical Waves of Light,' *Phil. Mag.* June, 1884.

the rotations are

$$0, \quad \frac{2\pi}{\lambda} c \cos \frac{2\pi}{\lambda}(bt-x), \quad 0;$$

and the elementary rotation to which this gives rise is

$$\omega_2 = -\frac{\pi c}{\lambda^2 r} dS\,(1 + \cos\theta)\sin\psi \sin\frac{2\pi}{\lambda}(bt - r),$$

ψ being the angle between the axis of y and the radius vector r. This elementary rotation takes place about a line perpendicular to the radius vector, and lying in a plane containing it and the axis of y.

On passing from one medium to another the rotation is not necessarily continuous. The only surface conditions are that the displacements and the stresses are the same on the two sides of the surface of separation, and if the rigidity of the ether be different in the two media the rotations will be different also. But Professor Stokes's solution does not apply to this case, and for the case to which it does apply is complete.

Chapter VII.—The Scattering of Light by Small Particles.

§ 1. In his experiments on the light scattered from precipitated clouds of fine matter, Tyndall [1] showed that when the particles are sufficiently fine the light emitted laterally is blue in colour, and in a direction perpendicular to that of the incident beam it is completely polarised.

The full explanation of this was given by Lord Rayleigh in 1871 in a series of papers [2] having an important bearing on our present subject—the relation between the plane of polarisation and the direction of vibration of plane polarised light. Professor Stokes, in his paper on fluorescence,[3] had indicated the connection between the two questions.

For consider a beam travelling horizontally, and look at it vertically downwards: the scattered light is in great part polarised in the plane of reflection. If the scattering particles be small compared with the wave length of the incident light, the vibrations in an incident ray cannot be at right angles to those in a scattered ray. For the incident vibrations are affected by the dust particles, which in consequence of their very great mass relative to the ether remain practically at rest.

We may treat the problem as if the dust particles moved exactly as the ether which they replace would do, and then superpose on this motion an equal and opposite motion. The first motion will not affect the regular propagation of the waves. In consequence of the second the particles become centres of disturbance, and set up other motions in the ether. These other motions will depend on the direction of apparent motion of the dust particles, and the optical effect in any direction will depend on the component of the motion at right angles to that direction. Now, the reflected ray is polarised in the plane of reflexion. If, then, the

[1] Tyndall, *Phil. Mag.* (4), vol. xxxvii.

[2] J. W. Strutt, 'On the Light from the Sky, its Polarisation and Colour,' *Phil. Mag.* Feb. and April, 1871; 'On the Scattering of Light by Small Particles,' June, 1871.

[3] Stokes 'On the Change of Refrangibility of Light,' *Phil. Trans.* 1852.

vibrations be in the plane of polarisation they will be at right angles to those in the incident light, while if the vibrations be at right angles to the plane of polarisation, they will come from the component of the original vibration, which is at right angles to that plane. If, then, on this supposition as to the relation between plane of polarisation and direction of vibration the incident light be polarised at right angles to the plane of reflection—*i.e.*, in the case before us in a horizontal plane—the light scattered in the vertical direction should vanish, and this is found to be the case. This general reasoning is substantiated by Lord Rayleigh in the papers before us by mathematical reasoning, and, moreover, he shows that the intensity of scattered light in any direction varies inversely as the fourth power of the wave length.

This may be seen from a consideration of the dimensions involved.

The ratio of the two amplitudes in the scattered and incident vibration will be a number. It must also involve the volume of the dust particles, being directly proportional to it, and it also will be inversely proportional to r, the distance from the disturbance; it must therefore depend on $T/\lambda^2 r$.

The mathematical expression for the disturbance is found as follows:—Let D' be the density of the ether in the dust particles, D in the space surrounding them. Let the vibrations in the incident wave, when they strike the dust, be given by $A \cos \frac{2\pi}{\lambda} bt$. Then the acceleration is

$$-A\left(\frac{2\pi}{\lambda} b\right)^2 \cos \frac{2\pi}{\lambda} bt.$$

In order that the wave may pass on undisturbed through the parts where the density is D', force would require to be applied; the amount of the force will be

$$-A(D'-D)\left(\frac{2\pi b}{\lambda}\right)^2 \cos \frac{2\pi}{\lambda} bt$$

per unit volume, and hence a force

$$A(D'-D)\left(\frac{2\pi b}{\lambda}\right)^2 \cos \frac{2\pi}{\lambda} bt,$$

conceived to act at O, the position of the particle, gives the same disturbance as is caused by the particle. Now, we have seen in Professor Stokes's paper that a force $F \cos \frac{2\pi}{\lambda} bt$ per unit of volume produces a displacement at any other point given by

$$\zeta = \frac{F \sin \alpha}{4\pi b^2 D r} \cos \frac{2\pi}{\lambda}(bt - r),$$

which is this case comes to

$$\zeta = A \frac{D'-D}{D} \frac{T}{r\lambda^2} \sin \alpha \cos \frac{2\pi}{\lambda}(bt - r) \quad . \quad . \quad . \quad (90)$$

where α is the angle between the radius vector r and the direction of the force F, and the displacement takes place in the plane passing through the directions of the force and the radius vector, and is at right angles to the latter.

Lord Rayleigh's paper concludes with another proof of the formula which gives the motion due to a force acting parallel to the axis of z. Put for the force Ze^{int}, then the equations of motion become, when expressed in terms of the rotation,

$$\left.\begin{aligned}(b^2\nabla^2+n^2)\,\omega_3&=0\\(b^2\nabla^2+n^2)\,\omega_1&=\frac{dZ}{dy}\\(b^2\nabla^2+n^2)\,\omega_2&=-\frac{dZ}{dz}\end{aligned}\right\}\quad . \quad . \quad . \quad . \quad (91)$$

Hence

$$\omega_1=\frac{1}{4\pi b^2}\iiint Z\,\frac{d}{dy}\left(\frac{e^{-ikr}}{r}\right)dxdydz$$

where

$$k=\frac{2\pi}{\lambda}=\frac{n}{b},$$

and the integral extends over the space T, through which the force acts.

Within this space $\frac{d}{dy}\left(\frac{e^{-ikr}}{r}\right)$ is sensibly constant; and if ω be the resultant rotation which will take place about an axis perpendicular to the plane through z and the radius vector,

$$\omega=-\frac{ikTZ\sin\alpha}{4\pi b^2}\,\frac{e^{-ikr}}{r}.$$

Hence

$$\zeta=\int\omega dr=\frac{TF\sin\alpha}{4\pi b^2 r}\cos\frac{2\pi}{\lambda}(bt-r)\quad . \quad . \quad (92)$$

In the second paper mentioned above Lord Rayleigh points out that the cause of reflexion may be diminished rigidity rather than increased density, and that in this case a scattered ray might be composed of vibrations perpendicular to those of the incident ray; he then proceeds to describe experiments on the composition of the light of the sky, made with a view of showing that it is such as would result, according to the above formula, from light scattered by small particles. And in the third paper he discusses the motion in an elastic solid in which the density and rigidity vary from point to point.

The problem is solved for two media differing slightly in density and rigidity, and it is shown that in a direction normal to the incident ray the rotation in the scattered ray, when the incident vibrations are parallel to z, is given by

$$\omega^2=p^2\left(\frac{\Delta n}{n}\right)^2\frac{z^2}{r^2}+p^2\left(\frac{\Delta D}{D}\right)^2\frac{y^2}{r^2}\quad . \quad . \quad . \quad (93)$$

where

$$p=\frac{ik^3T}{4\pi}\frac{e^{-ikr}}{r}$$

Hence, if Δn and ΔD are both finite, the scattered light can never vanish in a plane normal to the incident ray.

Now we know from experiment that it does vanish, and hence either Δn or ΔD must be zero. If we put $\Delta D=0$, it can be shown from the general expression for the rotation that there are six directions along which the scattered ray vanishes, for the components of the rotation are given by—

$$\left.\begin{aligned}\omega_3 &= -p\frac{\Delta n}{r}\frac{yz}{r^2}\\ \omega_1 &= p\frac{\Delta n}{n}\frac{xy}{r^2}\\ \omega_2 &= p\frac{\Delta n}{n}\frac{z^2-x^2}{r^2}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (94)$$

Now, there is nothing in the experimental results which at all leads to such a conclusion. If the hypothesis of a variable density be adopted, and Δn be put zero, then,

$$\left.\begin{aligned}\omega_3 &= 0\\ \omega_1 &= p\frac{\Delta D}{D}\frac{y}{r}\\ \omega_2 &= p\frac{\Delta D}{D}\frac{x}{r}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (95)$$

and the light vanishes in one direction only, viz. that of the axis of z. This result, of course, agrees with that of the former paper, and we must conclude that Fresnel's explanation of the cause of reflexion is the true one, while MacCullagh's is false, and that in plane polarised light the vibrations are perpendicular to, not parallel to, the plane of polarisation. The theory as left in this paper does not explain the phenomenon of the residual blue discovered also by Tyndall, who found that at a certain stage in the growth of the particle causing the scattering some light is discharged by the cloud parallel to the direction of vibration of the incident light, and that this light is of a very intense blue tint.

Lord Rayleigh points out that this may be due to the higher powers of $\Delta D/D$, which have been omitted, and in a more recent paper, based on the electro-magnetic theory, he develops this point more completely.[1]

Chapter VIII.—General Conclusions.

§ 1. Space compels us to conclude with this the general account of recent work on optical theories based solely on the elastic solid theory. Special problems of various kinds have received their solution, but to these we can only allude; indeed, for several of them the general properties of wave motion with the principle of interference are all that are required. Such, for example, are the papers by Prof. Stokes, 'On the Theory of certain Bands seen in the Spectrum,'[2] 'On the Formation of the Central Spot in Newton's Rings beyond the Critical Angle.'[3]—This is shown, as was suggested by Lloyd, to be due to the surface disturbance, which takes the place of the refracted wave when the angle of incidence

[1] See p. 253.
[2] Stokes, *Phil. Trans.* 1848; *Math. and Phys. Papers*, vol. ii. p. 14.
[3] Stokes, *Camb. Phil. Trans.* vol. viii.; *Math. and Phys. Papers*, vol. ii. p. 56.

exceeds the critical angle.—'On the Perfect Blackness of the Central Spot in Newton's Rings, and on the Verification of Fresnel's Formulæ for the Intensities of the Reflected and Refracted Rays.'[1] In this paper is given the now well-known proof of Arago's law that light is reflected in the same proportion at the first and second surfaces of a transparent plate. 'On the Colours of Thick Plates,'[2] and 'On the Composition and Resolution of Streams of Polarised Light from different sources.'[3]

In his 'Investigations in Optics, with special reference to the Spectroscope,' published in the 'Philosophical Magazine' for 1879 and 1880, Lord Rayleigh has considered the application of the principles of the wave theory to geometrical optics, and the construction of optical instruments. A full account of these is given in the article 'Optics,' in the 'Encyclopædia Britannica.'

Professor Stokes's great paper on Fluorescence[4] is chiefly experimental. The cause of the phenomena is assigned to the vibrations set up by the incident light in the molecules of the fluorescent substance, which themselves react on the ether and emit the fluorescent light. According to Stokes the vibrations in this light are never of shorter period than those in the incident light; and he in a general way endeavours to account for this, and shows that if the force acting on a given matter molecule due to a given displacement be proportional to a positive integral power of the displacement other than the first, then the amplitude of the displacements would involve the period, and there would be a tendency to increase the amplitudes of vibrations of lower period than that of the incident light, and to decrease the amplitudes in the case of vibrations of higher period than that of the incident light. Thus, in a group of disturbed molecules we should expect all possible periods between two, the upper corresponding to the refrangibility of the incident light, the lower corresponding to the natural period of the molecules. This result, known as Stokes's law, has been the cause of much discussion. Some physicists[5] hold that they have found fluorescent substances which constitute an exception to it, while others,[6] who have carefully repeated the critical experiments, draw conclusions in accordance with the law; and the weight of the evidence is with the latter.

A general account of the principles of the elastic solid theory was given in his lectures at Baltimore last year by Sir William Thomson.[7] To these we shall return in the next section.

§ 2. In concluding this part of the report we may say, then, that while the elastic solid theory, taken strictly, fails to represent all the facts of experiment, we have learnt an immense amount by its development, and have been taught where to look for modifications and improvements. We may, I think, infer that the optical differences of bodies depend mainly on differences in the density or effective density of the ether in those bodies, and not on differences of rigidity. Fresnel's general theory of the cause of reflexion is thus seen to be true, and Green's theory of

[1] *Camb. and Dub. Math. Journal*, vol. iv.; *Math. and Phys. Papers*, vol. ii. p. 89.

[2] *Camb. Phil. Trans.* vol. ix.

[3] *Ibid.*

[4] Stokes, 'On the Change of Refrangibility of Light,' *Phil. Trans.*

[5] Lommel, *Pogg. Ann.* t. 143, p. 159; *Wied. Ann.* t. iii. viii. x.; Lubarsch, *Wied. Ann.* t. xi.

[6] Hagenbach, *Pogg. Ann.*; Lamansky, *Journal de Physique*, t. viii.; *Wied. Ann.* t. viii. and xi.

[7] Thomson, *Lectures on Molecular Dynamics.*

reflexion and refraction can be made to agree with experiment by the simple supposition that for longitudinal and transverse disturbances respectively, the ether in a transparent body is loaded differently. This same theory of the loading of the ether will not account for double refraction if we assume that the vibrations are strictly in the wave front. If, however, we admit that in a crystal the vibrations may be normal to the ray, instead of in the wave front, Fresnel's beautiful laws follow at once from the equations given by Lord Rayleigh, which are quite consistent with the theory of reflexion and refraction, but there is a difficulty in dealing with the pressural wave. Neither of the strict elastic solid theories of Green can be accepted as representing the facts of experiment, and the interesting modification of Green's theory suggested by De St. Venant fails also. In all there are too many constants for the requirements of the experimental results, and the theories do not indicate the meaning of the arbitrary relations between these constants with sufficient clearness and certainty.

The suggestions of Cauchy and Briot, with the elegant mathematics of Sarrau on the periodic distribution of the ether in a transparent body, lead to expressions for the relation between the refractive index and wave length which agree well with experiment so long as we steer clear of substances which present the phenomena of anomalous dispersion, but of this they give no account.

While the formulæ given by Cauchy and Eisenlohr seem to represent the laws of metallic reflexion with considerable exactness, the theory on which these formulæ rest, requiring as it does a negative value for the square of the refractive index, is inconsistent with the conditions of stability of an elastic solid.

Nor is it surprising that a simple elastic solid theory should fail. The properties we have been considering depend on the presence of matter, and we have to deal with two systems of mutually interpenetrating particles. It is clearly a very rough approximation to suppose that the effect of the matter is merely to alter the rigidity or the density of the ether. The motion of the ether will be disturbed by the presence of the matter; motion may even be set up in the matter particles. The forces to which this gives rise may, so far as they affect the ether, enter its equations in such a way as to be equivalent to a change in its density or rigidity, but they may, and probably will, in some cases do more than this. The matter motion will depend in great measure on the ratio which the period of the incident light bears to the free period of the matter particles. If this be nearly unity, most of the energy in the incident vibration will be absorbed in setting the matter into motion, and the solution will be modified accordingly.

PART III.

THEORIES BASED ON THE MUTUAL REACTION BETWEEN THE ETHER AND MATTER.

Chapter I.—THE PROPAGATION OF WAVES THROUGH TWO MUTUALLY INTERPENETRATING MEDIA.

§ 1. In the optical theories hitherto considered attempts have been made to account for the phenomena of reflexion, refraction, and dispersion by the hypotheses of modifications produced in the properties of the ether

by the reaction of the material particles of the medium through which the light was being propagated. According to Fresnel the density of the ether is affected, while according to Neumann and MacCullagh it is to changes in the rigidity that the effects are due.

In both cases the direct effects of the communication of momentum from the ether to the material particles of the transparent medium is not considered. Fresnel,[1] it is true, thought it 'probable' that the molecules of ponderable matter should partake of the movement of the 'ether which surrounds them on all sides,' and Cauchy,[2] in one memoir, deals with the motion of two mutually interpenetrating systems of molecules, but without arriving at any specially important result. Voigt[3] states that about 1865 F. Neumann was in the habit of treating, in his lectures, the system of simultaneous equations relating to the motion of ether and matter. Briot,[4] in his work on dispersion, considers the direct reaction between matter and ether particles, but in his final result equates, as we have seen,[5] the term expressing it to zero.

§ 2. In 1867 a paper was presented to the French Academy by M. Boussinesq[6] on the 'Théorie nouvelle des ondes lumineuses.' In this paper the dynamical effects of momentum communicated by the ether to the molecules of ponderable matter are considered as the cause of reflexion, refraction, polarisation, dispersion, &c.

The ether is treated as homogeneous, and of the same density and rigidity in all bodies, and it is supposed that when light enters a transparent medium the molecules of that medium may be set in vibration isochronously with those of the ether. We have thus to consider the forces acting on such a medium, and these may be divided into three parts: (1) those which arise from the elastic reactions of the ether, (2) those arising from the elastic reactions of the matter, and (3) those arising from the mutual action between matter and ether.

Now let us consider a small element of volume, containing both matter and ether. Let m be the density of the ether, μ of the matter, u, v, w the displacements of the ether in the element, U, V, W those of the matter. Then, using Green's notation, the force, measured parallel to the axis of x, arising from (1) will be per unit of volume—

$$(\mathrm{A}-\mathrm{B})\frac{d\theta}{dx}+\mathrm{B}\nabla^2 u,$$

where
$$\theta=\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}.$$

For the forces arising under (2) we have to consider that $m\frac{d^2u}{dt^2}$ and $\mu\frac{d^2\mathrm{U}}{dt^2}$ will be quantities of the same order; but μ is very great indeed compared with m, and hence U is very small compared with u. The

[1] 'Premier Mémoire sur la double réfraction,' *Œuvres complètes*, t. ii. p. 278.
[2] *Exercices d'Analyse*, t. i. p. 33.
[3] *Wied. Ann.* t. xvii. p. 473.
[4] *Essais sur la théorie mathématique de la lumière.* Paris: 1865.
[5] See p. 181.
[6] *C. R.* t. lxv. p. 235; *Liouville's Journal*, s. ii. t. xiii. p. 313. A most clear account of this theory is given by M. de St. Venant in the article already quoted, 'Théorie des ondes lumineuses,' *Ann. de Chim.* s. ix. t. xxv. p. 368 *seq.*

forces (2) depend on U and its differential coefficients, and it is assumed in the theory that in consequence of the excessive smallness of U they may be neglected. Again, let us suppose that the dimensions of the element of volume are large compared with the distance through which the action of an ether particle on a matter particle is appreciable. Then we may consider the mutual reaction between matter and ether as confined entirely to the element of volume considered, the actions taking place across the surfaces of the element will just balance each other, and hence, if we consider the matter and ether as one system, the force (3) will be zero, and the equations of motion will be

$$m\frac{d^2u}{dt^2}+\mu\frac{d^2\mathrm{U}}{dt^2}=(\mathrm{A}-\mathrm{B})\frac{d\theta}{dx}+\mathrm{B}\nabla^2u,\ \text{etc.} \quad . \quad . \quad (1)$$

U is here the displacement of the matter occupying the same element of volume as the ether, whose displacement is u, but all the displacements being very small, it is assumed that we may treat U and u as the displacements of the matter and ether, which when at rest occupy the same element of volume. Thus U, V, W are functions of u, v, w and their differential coefficients with respect to x, y, z, the initial co-ordinates, and may be expanded in terms of these, and it remains to find the form of the expansion.

Conditions are, of course, imposed by the fact that the medium is isotropic, and it is shown that so far as second differential coefficients we may write

$$\mathrm{U}=\mathrm{A}u+\mathrm{C}\frac{d\theta}{dx}+\mathrm{D}\nabla^2u,\ \text{etc.} \quad . \quad . \quad . \quad (2)$$

On substituting this value of U, in the equation of motion, and assuming $u=\mathrm{M}e^{i\frac{2\pi}{\tau}\left(t-\frac{mx+ny+pz}{w}\right)}$ etc., we obtain

$$(\rho+\rho_1\mathrm{A})\frac{d^2u}{dt^2}=\left(\lambda+\mu+\frac{4\mathrm{C}\pi^2\rho_1}{\tau^2}\right)\frac{d\theta}{dx}+\left(\mu+\frac{4\mathrm{D}\pi^2\rho_1}{\tau^2}\right)\nabla^2u \quad . \quad (3)$$

And these equations, of course, give a normal wave travelling with a velocity $[\{\lambda+2\mu+4(\mathrm{C}+\mathrm{D})\pi^2\rho_1/\tau^2\}/(\rho+\mathrm{A}\rho_1)]^{\frac{1}{2}}$, and a transverse wave with velocity $[\{\mu+4\mathrm{D}\pi^2\rho_1/\tau^2\}/(\rho+\mathrm{A}\rho_1)]^{\frac{1}{2}}$.

These velocities vary with the period of vibration in a manner which agrees, at least approximately, with experiment. It is clear that the coefficient A is positive, while the experimental fact that the velocity increases with the period shows that D is negative. The condition that A is positive merely implies that the ether tends to move the matter particles in the same direction as it moves in itself.

If we suppose that the medium is not isotropically symmetrical, while at the same time it is such that the expressions retain the same form when two of the axes are turned through a small angle about the third, then terms $\mathrm{B}\left(\frac{dv}{dz}-\frac{dw}{dy}\right)$ come into the value for U, and these, it is shown, would cause the medium to produce rotation of the plane of polarisation of a plane polarised ray traversing it. This rotation would vary approximately inversely as the square of the period, in accordance with the law discovered by Briot. By introducing higher differential coefficients into

the value of U in terms of u, etc., it is shown that these approximate laws become, respectively,

$$V^2 = V_0^2\left(1 + \frac{e'}{\tau^2} + \frac{e''}{\tau^4} + \dots\dots\right) \quad . \quad . \quad . \quad (4)$$

V being the velocity, and V_0, ϵ, etc. constants, while for ψ, the rotation produced by a length z of the substance, he finds

$$\psi = \frac{f}{\tau^2}\left\{1 + \frac{f'}{\tau^2} + \frac{f''}{\tau^4} + \dots\dots\right\} \quad . \quad . \quad (5)$$

For the explanation of double refraction Boussinesq supposes that the constants in the above formula giving U, V, W in terms of u, v, w may be functions of the direction of displacement; but, arguing from the relative importance of A, C, and D in the ordinary theory of refraction (refraction is due to the existence of A, dispersion only to that of D), he supposes that we may to a first approximation treat C and D as constants, while we consider A as a function of the direction, and write for the three axes of symmetry, the existence of which is assumed, the values $A(1 + \alpha)$, $A(1 + \beta)$, and $A(1 + \gamma)$.

This leads to the equations—

$$\left.\begin{aligned} \frac{d^2u}{dt^2} &= K(1 + a)\frac{d\theta}{dx} + L(1 + a)\nabla^2 u \\ \frac{d^2v}{dt^2} &= K(1 + b)\frac{d\theta}{dx} + L(1 + b)\nabla^2 v \\ \frac{d^2w}{dt^2} &= K(1 + c)\frac{d\theta}{dx} + L(1 + c)\nabla^2 w \end{aligned}\right\} \quad . \quad . \quad (6)$$

K, L, a, b, c being functions of the other constants. It is clear that these are the same equations as were given by Lord Rayleigh,[1] and which have been already considered. The wave surface they lead to is not Fresnel's, at least if we suppose the vibrations to be necessarily transversal.

By retaining the terms involving the coefficient B, the elliptic polarisation produced by quartz in directions oblique to the axis is explained. The formula for the difference in velocity in the two elliptically polarised waves traversing the crystal in any given direction agrees closely with that given by MacCullagh. In this case the squares of the velocities parallel to the axis are given by the expression $N\left(1 \pm \frac{2\pi k}{\tau\sqrt{N}}\right)$, while the velocities in a direction making an angle θ with the axis depend on the equation

$$\omega^2 = N + \frac{M - N}{2}\sin^2\theta + \frac{2\pi^2k^2}{\tau^2}$$
$$\pm\frac{1}{2}\sqrt{\left[(M - N)^2\sin^4\theta + \frac{8\pi^2k^2}{\tau^2}\left\{2N + (M - N)\sin^2\theta\right\}\right]} \quad . \quad (7)$$

[1] See p. 179.

which can also be expressed in terms of the principal velocities at right angles to the axis, for if ω_1, ω_2 be the values of these, we have

$$\left.\begin{aligned} M + N &= \omega_1{}^2 + \omega_2{}^2 - \frac{4\pi^2 k^2}{\tau^2} \\ (M - N)^2 &= (\omega_1{}^2 - \omega_2{}^2)^2 - \frac{8\pi k^2}{\tau^2}(\omega_1{}^2 + \omega_2{}^2) \end{aligned}\right\} \quad . \quad (8)$$

The laws obtained in this paper are further developed in a second and third in the same journal. In this third paper, Boussinesq [1] points out the necessity of including in the expression for U in terms of u differential co-efficients of u, v, w with respect to the time, and shows that the phenomena of magnetic rotation can be accounted for by putting in the case of a wave travelling parallel to z—

$$\left.\begin{aligned} U &= Au - \mathfrak{B}\frac{dv}{dt} \\ V &= Av + \mathfrak{B}\frac{du}{dt} \\ W &= Aw \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (9)$$

while the phenomena presented by refraction at the surface of a moving body are explained on the supposition that in finding d^2U/dt^2 we have to take into account the visible motion of the body, and write

$$\frac{d}{dt} = \left(\frac{d}{dt} + L\frac{d}{dx} + M\frac{d}{dy} + N\frac{d}{dz}\right) \quad . \quad . \quad . \quad (10)$$

L, M, N being the components of the velocity at the point x, y, z; it is shown that in cases in which L, M, N are small compared with ω', the apparent velocity of light in the body is

$$\omega' = \omega + \frac{\mu^2 - 1}{\mu^2}\overline{V},$$

μ being the refractive index and $\overline{V}$ the velocity of the body in the direction in which the light is travelling. This, of course, is the formula given by Fresnel.

§ 3. M. de St. Venant,[2] in the article already quoted, sums up his criticism of the theory as follows: 'Les deux hypothèses principales de cette théorie nouvelle me semblent bien près de s'élever à la hauteur de choses démontrées.' At the same time there remains the difficulty pointed out by Sarrau [3] of explaining on mechanical principles how the various terms in U, V, W arise, and on what physical phenomena the mechanical forces brought into action depend.

§ 4. A further step in the progress of the theory was brought about by the discovery of anomalous dispersion by Christiansen [4] in 1870. Le

[1] Boussinesq, *Liouville's Journal*, t. xiii. pp. 340, 425.

[2] De St. Venant, 'Sur les diverses méthodes de présenter la théorie des ondes lumineuses,' *Ann. de Chimie*, t. xxii.

[3] 'Théorie des ondes lumineuses,' *Ann. de Chim.* (4), t. xxvii. p. 272.

[4] *Pogg. Ann.* t. 141, p. 479; t. 143, p. 250.

Roux [1] had found that vapour of iodine refracted red light more strongly than violet, and Christiansen, in the paper quoted, announced the result that for a solution of the aniline dye fuchsin in alcohol the refractive index increases from the Fraunhofer line B to D, then sinks rapidly as far as G, and increases again beyond. The experimental investigation of the subject was continued by Kundt,[2] who proved that this anomalous dispersion was marked in all substances showing strong surface coloration, and that there was an intimate relation between it and the absorptive power of the substance. As the result of his experiments, Kundt was able to lay down the rule that in going up the spectrum, from red to violet, below an absorption band the deviation is abnormally increased by the absorption, while above the band the deviation is abnormally decreased. Kundt has been able to see this abnormal effect produced by the absorption of sodium light.

On the old theory of dispersion, as developed by Cauchy and others, this effect was inexplicable. Boussinesq, it is true, had explained the phenomena in vapour of iodine by saying that it implied that the coefficient D was positive; and here, in a way, lay a germ of the truth, for the mutual reaction theory lends itself readily to a partial explanation of the whole.

§ 5. Such an explanation was first given by Sellmeyer. He had been led to expect the effect from theoretical reasons in 1866,[3] and had endeavoured to discover it in a fuchsin solution, but without success. The action between the ether and matter is a periodic one of the same period as the light-wave traversing the ether. Owing to the enormous density of the matter compared with the ether its motion will in general be negligeably small; but if it should happen that the period of the natural vibrations of the matter particles coincides with that of the incident disturbance this will no longer be the case. The energy of the light-vibration will be absorbed by the matter, and this absorption will tend to react on the light-disturbance, and will, it can be shown, increase the refractive power of the medium for disturbances of greater period than the critical one, and decrease it for disturbances of less period.

The problem is much the same as that of a pendulum the point of support of which is undergoing a small periodic disturbance. If the period of the disturbance be greater than that of the natural vibration of the pendulum the reaction of the pendulum on its support will tend to quicken the motion of the latter, and *vice versâ.*

Sellmeyer, in the papers referred to,[4] published in 1872, after a most clear and able discussion of the difficulties of the elastic solid theories, adopts the hypothesis that the ponderable atoms vibrate, but with much smaller amplitudes than the ether particles. He then proceeds to consider the mechanism by which this is brought about. As with Boussinesq, the ether is supposed to have the same rigidity and density everywhere. The ether particles act directly on the matter particles, and in consequence of the vibrations of the former the equilibrium positions of the latter are

[1] *Ann. de Chim.* S. III. t. xli. p. 285.

[2] *Pogg. Ann.* t. 142, p. 163; t. 143, pp. 149, 259; t. 144, p. 128; t. 145, pp. 17 and 164.

[3] Sellmeyer, *Pogg. Ann.* t. 142, p. 272.

[4] Sellmeyer, 'Ueber die durch die Æther-Schwingungen erregten Mitschwingungen der Körpertheilchen und deren Rückwirkung auf die erstern, besonders zur Erklärung der Dispersion und ihrer Anomalien,' *Pogg. Ann.* t. 145, pp. 399, 520; t. 147, pp. 386, 525.

disturbed and execute small harmonic vibrations; but the matter particles themselves will not generally coincide with their positions of instantaneous rest, and so we have to consider their vibrations about these positions. The equilibrium position of the matter at any instant is made to depend on the configuration of the ether at that instant, and may clearly be expressed, under the given circumstances, as a simple harmonic function of the time, so that if ξ_0, η_0, ζ_0 be the equilibrium co-ordinates at time t of a given matter particle of mass m', we may put

$$\xi_0 = a_0 \sin 2\pi \frac{t+\alpha}{\tau} \quad . \quad . \quad . \quad . \quad (11)$$

The amplitude a_0 will be very small.

The force acting on the particle m' is then considered on the assumption that the action between two particles of ether and matter respectively depends solely on the distance, and may be expressed by $mm'f(r)$, and it is shown that, supposing that $f(r)$ is a continuous function of the co-ordinates,[1] the force per unit mass tending to draw m' to its instantaneous position of equilibrium is

$$X = \frac{4\pi^2}{\delta^2}(\xi - \xi_0) \quad . \quad . \quad . \quad . \quad (12)$$

where δ is a quantity depending on f and the configuration of the medium, which may be a function of the direction. Thus, for an isotropic medium we have as the equation of motion of the matter particles—

$$\frac{d^2\xi}{dt^2} = -\frac{4\pi^2}{\delta^2}\left\{\xi - a_0 \sin \frac{2\pi}{\tau}(t+\alpha)\right\},$$

which leads, of course, to the integral

$$\xi = \frac{\tau^2}{\tau^2 - \delta^2} a_0 \sin \frac{2\pi}{\tau}(t+\alpha) + b \sin \frac{2\pi}{\delta}(t+\beta) \quad . \quad . \quad (13)$$

except when $\tau = \delta$, when

$$\xi = -\pi \frac{\delta}{t} a_0 \cos \frac{2\pi}{\delta}(\tau + \alpha) + b \sin \frac{2\pi}{\delta}(t+\beta) \quad . \quad . \quad (14)$$

The question as to the legitimacy of the assumption involved in the equation

$$\xi_0 = a_0 \sin \frac{2\pi}{\tau}(t+\alpha)$$

is then discussed, and it is finally shown that it is correct.

Again, it follows with great probability, from the experiments of Fizeau and Foucault [2] on interference with long difference of path, that in a ray of light the amplitude of vibration resolved in a given direction is not constant. We have, therefore, to treat a_0 as varying—slowly, it is true, compared with the rapidity of the vibrations—but still, it is probable, passing through many series of changes in one second.

This leads to the result that b, the amplitude of the natural vibrations

[1] See Stokes, *Brit. Assoc. Report*, 1862, p. 261.
[2] *Ann. de Chim.* s. iii. t. xxvi. p. 138.

of the matter particle, will always be small unless $\tau=\delta$. Omitting, then, these from consideration, it follows that

$$\xi=\frac{\tau^2}{\tau^2-\delta^2}\xi_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

and the vibrations thus set up in the matter are shown to be the cause of refraction; while if $\tau=\delta$ we have

$$\left.\begin{aligned}\xi&=-a\cos 2\pi\frac{t}{\delta}\\ \frac{da}{dt}&=\frac{\pi}{\delta}a_0\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

and these vibrations are the cause of absorption.

So far, then, the results of this investigation agree with those Boussinesq has given. They are, however, more general, in that they contemplate the possibility of the motions of the matter particles becoming appreciable, and so producing absorption. The next paper considers the question of the manner in which the action between the matter and ether affects the velocity of light. At first the direct effect of the matter on the ether is neglected, and the refractive power of the substance is found by considering the energy lost by the ether and gained by the matter in each vibration. The refractive power is measured by n^2-1, where n is the refractive index.

Now consider a volume so small that all the ether particles in it may be treated as in the same phase, so large that it contains many matter particles, and suppose the reactions considered confined to the ether and matter of this element.

Then it can be shown that if m' be the density of the ether, a' the amplitude of its vibration, the energy lost by the ether is $(n^2-1)2\pi^2m'a'^2/\tau^2$, while that gained by the matter is $2\pi^2\{\Sigma m\tau^2a_0{}^2/(\tau^2-\delta^2)\}/\tau^2$, whence the important formula

$$n^2-1=\frac{\Sigma m\dfrac{\tau^2}{\tau^2-\delta^2}a_0{}^2}{m'a'^2} \quad . \quad . \quad . \quad . \quad . \quad (17)$$

is obtained.

We may write this—

$$n^2-1=\Sigma\frac{K}{\dfrac{1}{\delta^2}-\dfrac{1}{\tau^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

where by Σ we mean that all the possible values of δ, the free period of the matter particles, are to be taken into consideration. Now let us suppose that τ is greater than δ, and that the matter particles have only one free period, then the denominator of the fraction is positive, and decreases as τ approaches δ. The refractive power, therefore, increases as the period decreases (*i.e.*, as we go up the spectrum), and as τ approaches the critical value δ (*i.e.*, as we near the absorption band) the refractive power is abnormally increased. Above the absorption band, supposing there be but one, the fraction is negative, and decreases numerically in value as τ is still further decreased; and until τ reaches a value for which $1/\tau^2=1/\delta^2+K$, n is imaginary.

As τ decreases still further the refractive power increases, but the refractive index is less than unity.

The presence of a second absorption band above the first will, of course, modify the conclusions. The change in refractive power is perhaps best illustrated by a curve, as is done in Sellmeyer's paper. For the case above considered take values of the refractive power (n^2-1) for ordinates, and the reciprocals of the periods for abscissæ, then the equation in the case of one absorption band will be

$$y = \frac{K}{a-x},$$

where $a = 1/\delta^2$.

Thus the curve is an hyperbola, with the axis of x and the line $x = a$ as asymptotes. If there be two absorption bands we have

$$y = \frac{K}{a-x} + \frac{L}{b-x},$$

and in this case there would be two critical values for x (viz., a and b) for which the refractive power would become infinite, and near which the dispersion would be anomalous.

In 1874 there appeared a paper by Ketteler[1] on the same subject. In an earlier paper he had enunciated as the law of dispersion in a gas the formula

$$n^2 - 1 = \frac{\alpha}{1 - \frac{\beta^2}{l^2}},$$

l being the wave length and α, β constants.

Further comparison with experiments had led him to the formulæ

$$\frac{1}{n^2} = K\,l^2 + A + \frac{B}{l^2 - C}$$

and he now shows that by a proper interpretation of the constants this will include the case of abnormal dispersion.

§ 6. The theory of the mutual reaction between the matter and ether was next developed by Helmholtz, and his work was continued by Lommel, Ketteler, and Voigt. The method adopted by Ketteler differs somewhat from those of the other three. Helmholtz[2] (in 1875), Lommel[3] (in 1878), and Voigt[4] (in 1883) start in the same manner to form the simultaneous equations satisfied by the displacements of the ether and matter particles in a given element of volume. Let u, v, w be the displacements of the ether particles of density m in an element of volume δv, U, V, W those of the matter particles of density μ.

The forces on m are, as in Boussinesq's paper referred to above,[5] considering only the components parallel to the x axis:—

[1] Ketteler, 'Das specifische Gesetz der sogenannten anomalen Dispersion,' *Pogg. Ann.* Jubelband, p. 166. See also p. 181.

[2] Helmholtz, 'Zur Theorie der anomalen Dispersion,' *Pogg. Ann.* t. 154, p. 582.

[3] Lommel, 'Theorie der normalen und anormalen Dispersion,' *Wied. Ann.* t. iii. p. 339.

[4] Voigt, 'Theorie des Lichtes für vollkommen durchsichtige Medien,' *Wied. Ann.* t. xix. p. 873.

[5] See p. 213.

(1) X', arising from external impressed forces;
(2) X, arising from the action of the other ether particles external to the element δv;
(3) A, arising from the action of the matter.
While for μ, the matter particle, they are:—
(1) Ξ', arising from external impressed forces;
(2) Ξ, arising from the action of the matter external to the element;
(3) A, arising from the direct action of the ether.
So that the equations of motion for an isotropic medium are—

$$\left.\begin{array}{l} m\dfrac{d^2u}{dt^2} = X' + X + A, \text{ etc.} \\ \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ m'\dfrac{d^2U}{dt^2} = \Xi' + \Xi + \mathrm{A}, \text{ etc.} \\ \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \end{array}\right\} \quad . \quad . \quad . \quad (19)$$

In all three theories the impressed forces are supposed to vanish, so that $X' = \Xi' = 0$. The action between the matter and ether is supposed to be confined to the element of volume considered—*i.e.* the dimensions of the element are treated as large compared with the distance at which the direct action of an ether particle on a matter particle is sensible.

This leads to the relation[1] $A + \mathrm{A} = 0$, independently of the value of A.

The term X springs from the ordinary elastic reaction of the ether. Helmholtz and Lommel, considering only a wave of displacement in the direction of x travelling parallel to z, write for this term

$$a^2\frac{d^2u}{dz^2},$$

while Voigt considers the general forms of the expression given by the ordinary elastic solid theory, which, of course, reduces for the case of an isotropic medium to

$$e\nabla^2u + e'\frac{d\delta}{dx},$$

where

$$\delta = \frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}.$$

For the forces represented by Ξ, Voigt again considers the general case of a strained elastic solid, while Helmholtz and Lommel after him write

$$\Xi = -a^2U - \gamma^2\frac{dU}{dt}.$$

For the proper values to be given to A and A there is great divergence of opinion shown in the three theories.

[1] In his paper Lommel—as has been pointed out by Ketteler, 'Optische Controversen,' *Wied. Ann.* t. xviii. p. 387, and Voigt, 'Bemerkungen zu Herrn Lommel's Theorie des Lichtes,' *Wied. Ann.* t. xvii. p. 468—really employs the condition $A - \mathrm{A} = 0$, for he estimates u and U in opposite directions. In his reply, *Wied. Ann.* t. xix. p. 908, Lommel endeavours to justify the signs used, but I think without success. The effect will be to change the sign of a coefficient in one of the terms.

Helmholtz supposes, 'um die Bewegungsgleichungen zu vervollständigen,' that A is proportional to the relative displacement of the ether and atoms in the element of volume, and writes, therefore,

$$A = \beta^2(U - u).$$

Lommel supposes that the action 'follows Newton's law of friction,' and depends on the relative velocity of the two; he puts, therefore,

$$A = \beta^2 \frac{d}{dt}(U - u).$$

The expression given by Voigt is much more complicated, and can best be considered later. Thus the equations we have to deal with are—

$$\left.\begin{aligned} m\frac{d^2u}{dt^2} &= a^2\frac{d^2u}{dz^2} + \beta^2(U-u) \\ \mu\frac{d^2U}{dt^2} &= -\beta^2(U-u) - a^2U - \gamma^2\frac{dU}{dt} \end{aligned}\right\} \quad . \quad . \quad (20)$$

(Helmholtz), and

$$\left.\begin{aligned} m\frac{d^2u}{dt^2} &= a^2\frac{d^2u}{dz^2} + \beta^2\frac{d}{dt}(U-u) \\ \mu\frac{d^2U}{dt^2} &= -\beta^2\frac{d}{dt}(U-u) - a^2U - \gamma^2\frac{dU}{dt}^* \end{aligned}\right\} \quad . \quad . \quad (21)$$

(Lommel).

The method of solution is the same in both. u and U, which, strictly, are the displacements of ether and matter in the same volume in the displaced condition, are treated as if they were the displacements of ether and matter having the same undisturbed co-ordinates x, y, z. This is legitimate, for U and u are both taken to be functions of the position of the wave front and the time only, and hence for all points on the same wave front U has at a given instant the same value.

Assume, then,

$$\left.\begin{aligned} u &= \mathfrak{A}e^{-kz+in(z-ct)/c} \\ U &= Ae^{-kz+in(z-ct)/c}\dagger \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (22)$$

k is the coefficient of absorption, c the velocity, and $2\pi/n$ the period of the vibration.

On substituting these values in Helmholtz's equations, we find

$$\frac{1}{c^2} - \frac{k^2}{n^2} = \frac{m}{a^2} - \frac{\beta^2}{a^2n^2} - \frac{\beta^4}{a^2n^2}\frac{\mu n^2 - a^2 - \beta^2}{(\mu n^2 - a^2 - \beta^2)^2 + \gamma^4 n^2} = F \text{ (say)} \quad . \quad (23)$$

and

$$\frac{2k}{cn} = \frac{\beta^4\gamma^2}{a^2n}\frac{1}{(\mu n^2 - a^2 - \beta^2)^2 + \gamma^4 n^2} = G \text{ (say)} \quad . \quad . \quad (24)$$

* In this equation the sign of β^2 has been changed from that given by Lommel in accordance with the remark on p. 221; but see Lommel's reply to Voigt, *Wied. Ann.* t. xix. p. 908.

† A, of course, no longer has the same meaning as above, but is the amplitude of the matter vibrations.

To solve these, put

$$\frac{1}{c} = \rho \cos \omega,$$

$$\frac{k}{n} = \rho \sin \omega.$$

Then

$$\left.\begin{aligned} \frac{1}{c^2} - \frac{k^2}{n^2} &= \rho^2 \cos 2\omega = F \\ \frac{2k}{cn} &= \rho^2 \sin 2\omega = G \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (25)$$

Thus the value of k, on which the absorption depends, is proportional to γ^2, the coefficient of dU/dt in the equation, and vanishes if γ^2 is zero; that is, if there be no frictional resistance to the matter motion. If k be at all appreciable, the light-disturbance will penetrate but a little way into the medium, so that for transparent media we may treat k, and therefore G, as small.

In this case we have

$$\frac{1}{c^2} = F + \frac{1}{4}\frac{G^2}{F} +, \text{ etc.},$$

while in the small term we may put for G/F the value $2kc/n$.

In these circumstances, then,

$$\frac{k}{c} = \frac{1}{2} nG = \frac{\beta^4\gamma^2}{2\alpha^2\mu^2} \cdot \frac{1}{(n^2 - \nu^2)^2 + 4(\nu^2 + \varpi^2)\varpi^2} \quad . \quad . \quad (26)$$

where

$$\left.\begin{aligned} \mu\nu^2 &= \alpha^2 + \beta^2 - \gamma^4/2\mu \\ \varpi^2 &= \gamma^4/4\mu^2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (27)$$

Thus, as n changes k/c is a maximum when $n = \nu$; if the corresponding values of k and c be k_0 and c_0, then

$$\frac{c_0}{k_0}\left\{1 + \frac{(n^2 - \nu^2)^2}{4\varpi^2(\nu^2 + \varpi^2)}\right\} = \frac{c}{k} \quad . \quad . \quad . \quad (28)$$

If the value of γ be zero, then, for $n = \nu$, k is infinite compared with c; all the light is absorbed.

At the same time A is large, and we have, in dealing with the motion of the matter particles, to consider the limit of $Ae^{-k_0 z}$.

Turning, now, to the refraction, let C be the velocity of light in free space, N the refractive index, and suppose that the term $\frac{1}{4}G^2/F$ may be neglected, then

$$N^2 = C^2F = \frac{C^2 m}{\alpha^2}\left[1 - \frac{\beta^2}{mn^2} + \frac{\beta^4(\nu^2 + 2\varpi^2 - n^2)}{m\mu n^2\{(\nu^2 - n^2)^2 + 4\varpi^2(\nu^2 + \varpi^2)\}}\right] \cdot \quad (29)$$

and the maxima and minima values of this expression lead to the limiting values of the refractive index.

These, it is shown, are given approximately by $n^2 - \nu^2 = \pm 2\nu\varpi$, which

correspond nearly to the maxima of absorption. Thus, as we go up the spectrum, the refractive power is a maximum for the value of n, given by $n^2 = \nu^2 - 2\nu\varpi$, and a minimum for $n^2 = \nu^2 + 2\nu\varpi$. There is, therefore, abnormal dispersion in the neighbourhood of the absorption band, but elsewhere the refractive index increases with n. Again, for large values of n we have $N^2 = C^2 m/a^2$. Now, if the density and the rigidity of the ether be the same in all bodies, we should have $C^2 = a^2/m$, and therefore in this case $N = 1$. Thus the light of shortest wave lengths would be transmitted without refraction, contrary to experimental results. Sellmeyer, however, pointed out a method of explaining this difficulty which would be consistent with the supposition that C^2 is equal to a^2/m. According to him, we must suppose that there is a strong absorption band somewhere just above the visible limits of the spectrum—that is to say, that the value of $\nu^2 - 2\nu\varpi$ is just beyond the limits of the visible spectrum, and that owing to this the refraction below the band is abnormally increased.

The paper closes with a method for constructing the form of the refraction and absorption curves.

Lommel's equations can be solved in a similar manner, and lead to similar formulæ. The two theories can best be compared with each other and with experiment by changing the notation slightly, and adopting that used by Ketteler[1] in his criticism of the same. Let us put, therefore,

$$\left.\begin{aligned} a^2 &= \mu\nu_1^{\,2} \\ \beta^2 &= B\nu_1^{\,2} \\ \gamma^2 &= \mu\nu_1 K \\ \nu_0^{\,2} &= \nu_1^{\,2}\left(1 + \frac{B}{\mu}\right) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (30)$$

Then Helmholtz's equations (23) and (24) become

$$\frac{1}{c^2} - \frac{k^2}{n^2} = \frac{m}{a^2}\left[1 - \frac{B}{m}\frac{\nu_1^{\,2}}{n^2} + \frac{B^2\nu_1^{\,4}(\nu_0^{\,2} - n^2)}{\mu m n^2\{(\nu_0^{\,2} - n^2)^2 + n^2\nu_1^{\,2}K\}}\right] \quad . \quad (31)$$

and

$$\frac{2k}{cn} = \frac{m}{a^2}\,\frac{B^2\nu^5 K}{\mu m n\{(\nu_0^{\,2} - n^2) + n^2\nu_1^{\,2}K^2\}} \quad . \quad . \quad . \quad (32)$$

and if we suppose λ, λ_1, λ_0 to be the wave lengths corresponding to the periods n, ν_1, and ν_0, we find

$$\left.\begin{aligned} F &= \frac{m}{a^2}\left[1 - \frac{B\lambda^2}{m\lambda_1^{\,2}} + \frac{\dfrac{B^2}{\mu m}\dfrac{\lambda^4}{\lambda_1^{\,4}}\left(\dfrac{\lambda^2}{\lambda_0^{\,2}} - 1\right)}{\left(\dfrac{\lambda^2}{\lambda_0^{\,2}} - 1\right)^2 + K^2\dfrac{\lambda^2}{\lambda_1^{\,2}}}\right] \\ G &= \frac{m}{a^2}\,\frac{\dfrac{B^2}{\mu m}K\dfrac{\lambda^5}{\lambda_1^{\,5}}}{\left(\dfrac{\lambda^2}{\lambda_0^{\,2}} - 1\right)^2 + K^2\dfrac{\lambda^2}{\lambda_1^{\,2}}} \end{aligned}\right\} \quad . \quad . \quad (33)$$

[1] Ketteler, 'Optische Controversen,' *Wied. Ann.* t. xviii. p. 387.

while the ratio of the amplitudes is given by

$$A = \mathfrak{A}\frac{\frac{B}{\mu}\frac{\lambda^2}{\lambda_1^2}}{\sqrt{\left\{\left(\frac{\lambda^2}{\lambda_0^2}-1\right)^2+K^2\frac{\lambda^2}{\lambda_1^2}\right\}}} \quad . \quad . \quad . \quad (34)$$

We can give a sort of physical meaning to the constants in these formulæ as follows: λ_1 is the wave length of the natural vibrations of the matter, freed from any action of the ether; λ_0 is their wave length on the supposition that the action between the ether and matter is proportional to the displacement, while the ether remains fixed; while ν_1 and ν_0 are the frequencies of these vibrations. B vanishes when there is no matter present, and since the expression shows that B/m is a number, it is probable that B will be proportional to the matter density; while K is a number on which the strength of the frictional retardation depends.

The quantity λ_1, the wave length of the free vibrations (*i.e.* the distance the light-wave travels in a natural free matter period) is immensely great compared with λ, so that A is small compared with $\mathfrak{A}$, except in the cases in which λ does not differ greatly from λ_0.

It will be seen at once that the formula for F, on which, when the absorption is small, the refractive index depends, in terms of the wave length is very complicated. I am not aware that any attempts have been made to compare it carefully with theory.

In the cases in which K is small (*i.e.*, for transparent media) λ_0 will be an approximate lower limit to the wave length of the light transmitted.

If we integrate the equation given by Lommel's hypothesis, modified so as to agree with the principle of action and reaction, we find

$$F^* = \frac{m}{a^2}\left[1 - \frac{\frac{B'^2}{m\mu}\frac{\lambda^2}{\lambda_1^2}\left(\frac{\lambda^2}{\lambda_1^2}-1\right)}{\left(\frac{\lambda^2}{\lambda_1^2}-1\right)^2+\left(\frac{B'}{\mu}-K\right)^2\frac{\lambda^2}{\lambda_1^2}}\right] \quad . \quad . \quad . \quad (35)$$

where B′ is a constant related to the β^2 of Lommel's equations in the same manner as B is to β^2 above. If, however, we take Lommel's expression strictly, to which he still adheres,[1] the sign of the fractional expression must be changed.

If we retain the negative sign the formula (35) fails to represent the facts. Neglecting for a moment the effect of absorption, and supposing the ether to be of the same rigidity and density as in free space, the square of the refractive index will be rather less than unity for the longest waves; it will then decrease to a minimum value, which will be positive, and then rise rapidly through the absorption band, for which $\lambda = \lambda_0$, reaching a maximum a little above the band, from which it will again fall. Absorption effects will only slightly modify these conclusions. Thus the spectrum above the band ought to be more refracted than that below, and except just near the band the refractive index should decrease as the wave length decreases. This is fatal to the theory in this form. In its

* This becomes the expression given by Lommel on substituting $B'/\mu - K = \epsilon^2$, $\lambda_1 = \lambda_0$, $B' = m(K-\epsilon)$, and interchanging m and μ.

[1] Lommel, 'Zur Theorie des Lichtes,' *Wied. Ann.* t. xix. p. 908.

original form it is not open to this criticism, and accounts for the facts, but its fundamental equations are hopelessly at variance with Newton's third law, so long, at least, as we suppose the mutual reaction limited to that between the matter and ether in the element of volume considered —that is, so long as we may suppose that there are many molecules in an element of volume. The original formula for dispersion leads to results which, as Lommel[1] has shown, agree fairly with experiment; and by carrying the approximation a step further the agreement becomes closer still, so that his fundamental equations might be taken as an empirical representation of the facts with some approach to the truth.

Voigt's theory differs from these mainly in the values assigned to A and A and the methods by which those values are obtained; and before treating at length of it, it will conduce to clearness if we consider Ketteler's theory, the results of which have considerable resemblance to the two already mentioned, while the work itself is earlier than Voigt's.

§ 7. Ketteler[2] is the author of a large number of papers on this subject, and the form in which he has presented his theory has varied somewhat, though the central idea which he has endeavoured to express has remained the same throughout. The idea seems to be as follows. The exact expression of the action between matter and ether, the A and A of the fundamental equations, is unknown to us, and we must therefore endeavour to eliminate it from the equations. This we can effect by considering the work done per unit time on the whole system, into which, of course, the mutual reactions will not come, and equating it to the rate of change of the kinetic energy. This alone, of course, will only lead to one equation, and though in some of his work Ketteler appears to obtain two out of it, this, as we shall see shortly, is done by the aid of an additional hypothesis.

It is, however, not till some of the later papers that these views are completely developed. In his first paper[3] he assumes that the action of the matter on the ether is to increase its rigidity by the quantity ϵa, and to introduce a resistance $a\kappa\rho$, where ϵ is constant for the medium and a is some unknown function of its dynamical condition, while the forces on the matter are $a(\epsilon'\nabla^2\rho' + \kappa'\rho')$, ρ' being the matter displacement, so that, considering the motion parallel to x, we have for the ether

$$m\frac{d^2\rho}{dt^2} = (e + \epsilon a)\frac{d^2\rho}{dx^2} + a\kappa\rho$$

and for the matter

$$m'\frac{d^2\rho'}{dt^2} = a\left(\epsilon'\frac{d^2\rho'}{dx^2} + \kappa\rho'\right) \qquad . \quad . \quad . \quad (36)$$

Arguments similar to those employed by Sellmeyer lead to the equation

$$\mathrm{N}^2 - 1 = \frac{m'\rho'^2}{m\rho^2} \qquad . \quad . \quad . \quad . \quad . \quad (37)$$

and on multiplying the first of the equations of motion by ρ, the second

[1] Lommel, 'Ueber das Dispersionsgesetz,' *Wied. Ann.* t. xiii. p. 353.

[2] Since the above was sent to press, Ketteler has published his optical theories in the form of a book, *Theoretische Optik*: Braunschweig, F. Vieweg und Sohn, 1885. The fundamental equations are formed as indicated below (Equation 43), and the remarks made in connection with that section apply.

[3] Ketteler, 'Versuch einer Theorie der (anomalen) Dispersion des Lichtes in einfach- und doppelt-brechenden Medien,' *Carl Repertorium*, t. xii. p. 322.

by ρ', we find that the condition (37) requires the coefficient of a to vanish separately, and we are led to the two equations

$$\left.\begin{aligned} m\rho\,\frac{d^2\rho}{dt^2} + m'\rho'\,\frac{d^2\rho'}{dt^2} &= e\rho\,\frac{d^2\rho}{dx^2} \\ \rho\left(\epsilon\frac{d^2\rho}{dx^2} + \kappa\rho\right) + \rho'\left(\epsilon'\frac{d^2\rho'}{dx^2} + \kappa'\rho'\right) &= 0 \end{aligned}\right\} \quad . \quad . \quad (38)$$

and these are the two fundamental equations of the theory, from which an expression is found for the refractive index in terms of the wave lengths and constants, viz. :—

$$N^2 = N^2_{\infty} + \Sigma\,\frac{D}{\frac{\lambda^2}{\lambda_1{}^2} - 1} \quad . \quad . \quad . \quad . \quad . \quad (39)$$

where the Σ must be taken to include the different kinds of matter particles in the medium. So far, at any rate, the theoretical bases of these expressions are no more secure than those of Lommel and Helmholtz. The dispersion equation, however, is much more simple than that given by Helmholtz, and agrees well, as Ketteler [1] has himself shown, with experiment.

A second paper [2] develops some further consequences and traces the form of the dispersion curve in various circumstances.

In a third paper [3] the principles of the theory are stated and applied to doubly refracting media, but the equations from which he starts—the same as those given above, only written with three co-ordinates—do not express the physical facts which they are intended to do, and the theory deduced can only be considered as empirical.

A further attempt, based on this principle of energy alone, is made in a more recent paper [4] to establish two independent equations. Thus, the ether mass in an element being displaced a distance ds, the matter mass ds'; then the equation

$$m\,\frac{d^2\rho}{dt^2}\,ds + m'\,\frac{d^2\rho'}{dt^2}\,ds' = e\,\frac{d^2\rho}{dz^2}\,ds \quad . \quad . \quad . \quad (40)$$

is supposed to express the law of the conservation of energy for the ether motion; it neglects entirely the forces on m' from the action of neighbouring matter. The conservation of energy principle alone will give but one equation when applied to the system, though it will of course eliminate the unknown reactions between matter and ether.

Similar remarks must be made with regard to other papers [5] dealing with the formation of the fundamental equations. The equations D of the last article referred to are only true on the assumption that the

[1] See p. 181.

[2] Ketteler, 'Zum Zusammenhang zwischen Absorption und Dispersion,' *Pogg. Ann.* t. 160, p. 466.

[3] Ketteler, 'Zur Theorie der Dispersion und Absorption des Lichtes in doppeltbrechenden Mitteln,' *Pogg. Ann.* Ergänzung, Band viii. p. 444.

[4] Ketteler, 'Das Dispersionsgesetz,' *Wied. Ann.* t. vii. p. 658.

[5] Ketteler, 'Theorie der absorbirenden Anisotropen-Mittel,' *Monatsber. der Königl. Akad. der Wiss. zu Berlin*, Nov. 13, 1879; 'Optische Controversen,' *Wied. Ann.* t. xviii. p. 387; 'Erwiederung auf Herrn Voigt's Kritik,' *Wied. Ann.* Bd. xxi. p. 178.

reaction of the matter on the ether produces a force $-m'C'\frac{d^2\rho'}{dt^2}$,* while the action of the ether on the matter is expressed by a force $-mC\frac{d^2\rho}{dt^2}$; and, indeed, in his most recent work on the subject [1] he realises clearly that the energy principle only leads him to one equation, viz. :—

$$m\frac{d^2\rho}{dt^2}d\rho + m'\frac{d^2\rho'}{dt^2}d\rho' = e\nabla^2\rho d\rho - \kappa\rho' d\rho' \quad . \quad . \quad (41)$$

e being the rigidity of the ether in free space—and then combines with this a 'second equation relating to the special mode of action of the matter particles, which can be no other than the renowned fundamental equation of Bessel's theory of the pendulum'; this may be written

$$m\frac{d^2\rho}{dt^2}C + m'\frac{d^2\rho'}{dt^2} = -\kappa\rho' \quad . \quad . \quad . \quad . \quad . \quad (42)$$

It is then further assumed that the matter particles exert a force $\beta m'\rho'$ on the ether, and the equations finally become—

$$\left.\begin{aligned} m\frac{d^2\rho}{dt^2} - m'C_0\frac{d^2\rho'}{dt^2} &= e\nabla^2\rho + \beta m'\rho' \\ m'C_0\frac{d^2\rho}{dt^2} + m'\frac{d^2\rho'}{dt^2} &= -\left(\kappa\rho' + \gamma\frac{d\rho'}{dt}\right) \end{aligned}\right\} \quad . \quad . \quad (43)$$

leading to the equation

$$\left. N^2 - N^2_\infty = \frac{N^2_\infty - N_0^2 + \sqrt{-1}(N^2_\infty - 1)K\frac{\lambda}{\lambda_1}}{\frac{\lambda^2}{\lambda_1^2} - 1 - \sqrt{-1}K\frac{\lambda}{\lambda_1}}\right\} \quad . \quad . \quad (44)$$

where K is a quantity depending on γ. When K is small, as is always the case in transparent media, this becomes the formula already mentioned, which has been tested over so wide a range by Ketteler. It is clear from these last equations that the action of the matter on the ether is represented by $m'C_0\frac{d^2\rho'}{dt^2} + \beta m'\rho'$, and of the ether on the matter by $m'C_0\frac{d^2\rho}{dt^2}$. It is difficult to conceive of the mechanical principles which would lead to these terms as they stand, and the occurrence of the imaginary quantity in the expression for the refractive index, to which they lead, is a blot on the theory.

§ 8. In fact, the form of the equations given in his earlier papers [2] leads to results which are more directly intelligible, while the equations themselves can, it seems to me, be established by the aid of a suggestion due to Ketteler himself ('Eine dritte Annahme,' p. 397).

For, taking the notation employed when considering Helmholtz and

* In Ketteler's paper ξ, ξ' are used for the displacements. I have retained ρ, ρ', in accordance with the notation already employed.

[1] 'Zur Dispersionstheorie des Lichtes,' *Wied. Ann.* t. xxi. p. 199. See also Ketteler, *Theoretische Optik*, p. 85, *et seq.*

[2] Ketteler, 'Optische Controversen,' *Wied. Ann.* t. xviii. p. 387.

Lommel, let us assume, according to this third supposition of Ketteler's, that the reaction between the ether and matter is proportional to the relative accelerations of the two. Helmholtz supposes it proportional to the relative displacements, Lommel to the relative velocities. In this case, then,

$$A = -\beta^2 \frac{d^2}{dt^2}(u - U),$$

and hence

$$m\frac{d^2u}{dt^2} + \beta^2\frac{d^2}{dt^2}(u - U) = X,$$

$$\mu'\frac{d^2U}{dt^2} - \beta^2\frac{d^2}{dt^2}(u - U) = \Xi,$$

Thus

$$m\frac{d^2u}{dt^2} - \frac{\beta^2 m}{m+\beta^2}\frac{d^2U}{dt^2} = \frac{mX}{m+\beta^2} \quad . \quad . \quad . \quad (45)$$

$$\frac{\mu\beta^2}{\mu-\beta^2}\frac{d^2u}{dt^2} + \mu\frac{d^2U}{dt^2} = \frac{\mu}{\mu-\beta^2}\Xi \quad . \quad . \quad . \quad (46)$$

And, with Ketteler's assumptions as to the forces X and Ξ, these may be written as follows—

$$\left.\begin{aligned} m\frac{d^2u}{dt^2} + \mu C'\frac{d^2U}{dt^2} &= a^2\frac{d^2u}{dz^2} \\ \mu C\frac{d^2u}{dt^2} + \mu\frac{d^2U}{dt^2} &= -\left(a^2U + z^2\frac{dU}{dt}\right) \end{aligned}\right\} \quad . \quad . \quad . \quad (47)$$

which are the same in form as Ketteler's equations, though a^2 is not the rigidity of the free ether, while there is a relation between C and C′, for

$$\left.\begin{aligned} C' &= -\frac{m}{\mu}\frac{\beta^2}{m+\beta^2} \\ \text{and} \qquad C &= \frac{\beta^2}{\mu-\beta^2} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (48)$$

However, this does not matter, for it is the product CC′ which comes into the fundamental equations of the solution, and we find

$$\frac{1}{c^2} - \frac{k^2}{n^2} = F = \frac{m}{a^2}\left[1 + \Sigma\frac{D\left(\frac{\lambda^2}{\lambda_1^2} - 1\right)}{\left(\frac{\lambda^2}{\lambda_1^2} - 1\right)^2 + K^2\frac{\lambda^2}{\lambda_1^2}}\right] \quad . \quad . \quad (49)$$

$$\frac{2k}{cn} = \frac{m}{a^2}\Sigma\frac{DK\frac{\lambda}{\lambda_1}}{\left(\frac{\lambda^2}{\lambda_1^2} - 1\right)^2 + K^2\frac{\lambda^2}{\lambda_1^2}} \quad . \quad . \quad . \quad (50)$$

where $D = CC'$, and K is proportional to γ^2.

The quantity a^2/m is no longer the square of the velocity in free space, and cannot be put equal to unity, and, in fact, a^2/m will be the square of the refractive index for very long waves. Ketteler (p. 398)

seems to consider it an objection to his theory that it gives a value differing from unity to the refractive index for infinite waves, but the objection is not, I think, serious. As has been stated before, the dispersion equation given by his theory has been repeatedly tested by Ketteler,[1] and the agreement between theory and experiment is very satisfactory. Thus we may probably look upon this equation as one established empirically by his experiments, and while not agreeing with the reasoning employed by Ketteler in forming his equations of motion, may see in those equations the expression of a possible law of action between matter and the ether.

§ 9. Let us now turn to Voigt's work, which is of more recent date. He has been a severe critic of his predecessors, and objects strongly to various points in their work.

In his first paper[2] on the subject Voigt, following Boussinesq,[3] remarks that md^2u/dt^2 and $\mu d^2U/dt^2$ being quantities of the same order, U will be very small compared with u because μ is very large compared with m; it is therefore not necessary to introduce terms involving U into the differential equations for u. To this we may reply, (1) that it is quite possible that the coefficients of U and its differential coefficients involve μ the matter density, and that in consequence the terms in question are comparable with md^2u/dt^2, and (2) that in the critical case near the absorption band the value of U becomes large, and may be quite comparable with u.

Voigt also objects to the form adopted for Ξ in all the previous theories, viz. $-(\kappa U + \gamma dU/dt)$, pointing out that Helmholtz introduced the κU 'zur Vereinfachung der Rechnung,' and the $\gamma dU/dt$ to explain the transformation of light-energy into heat. If the ponderable matter is to be looked on as an elastic solid, then, according to Voigt, we ought to put for Ξ terms like $a^2\nabla^2 U + b^2 d\delta/dx$. To this Lommel replies[4] that the matter molecules each as a whole are not affected by the passage of the wave of light, but that intra-molecular or atomic motions are set up, and that the forces arising from these are represented by his terms, how he does not explain.

Of course, since it is assumed that $U = Ae^{kz + in(z-ct)/c}$, $\nabla^2 U = -(k + in/c)^2 U$, the difference between the two will only show itself in a change in the refraction formula.

The main criticism[5] of Ketteler's work relates to the method in which the equations are obtained. To this we have already referred.

§ 10. After these criticisms we turn to the consideration of Voigt's[6] own theory. His fundamental equations are, as we have seen,

[1] Ketteler, 'Constructionen zur anomalen Dispersion,' *Wied. Ann.* t. xi. p. 210; 'Einige Anwendungen des Dispersionsgesetzes auf durchsichtige, halbdurchsichtige und undurchsichtige Mittel,' *Wied. Ann.* t. xii. p. 363; 'Experimentale Untersuchung über den Zusammenhang zwischen Refraction und Absorption des Lichtes,' *Wied. Ann.* t. xii. p. 481; 'Photometrische Untersuchungen,' *Wied. Ann.* t. xv. p. 336.

[2] 'Bemerkungen zu Herrn Lommel's Theorie des Lichtes,' *Wied. Ann.* t. xvii. p. 468.

[3] See p. 213.

[4] Lommel, 'Zur Theorie des Lichtes,' *Wied. Ann.* t. xix. p. 908.

[5] Voigt, 'Ueber die Grundgleichungen der optischen Theorie des Herrn E. Ketteler,' *Wied. Ann.* t. xix. p. 691; 'Duplik gegen Herrn Ketteler,' *Wied. Ann.* t. xxi. p. 534; Ketteler, 'Erwiederung auf Herrn Voigt's Kritik,' *Wied. Ann.* t xxi. p. 178; 'Duplik gegen Herrn Voigt,' *Wied. Ann.* t. xxii. p. 217.

[6] Voigt, 'Theorie des Lichtes für vollkommen durchsichtige Medien,' *Wied. Ann.* t. xix. p. 873.

$$\left.\begin{aligned} m\frac{d^2u}{dt^2} &= \mathrm{X} + \mathrm{X}' + A \\ \mu\frac{d^2\mathrm{U}}{dt^2} &= \Xi + \Xi' + \mathrm{A} \end{aligned}\right\} \quad . \quad . \quad . \quad (51)$$

X' and Ξ' are each put equal to zero, and the condition $A + \mathrm{A} = 0$ is assumed; that is, it is supposed, as we have stated before, that the sphere of action of each ether particle on the matter is small compared with the dimensions of the element of volume considered.

An expression is then found for the rate at which work is being done on the compound medium, and the condition formed that this expression should be a function of the time only.

So far as the terms depending on the mutual reactions are concerned, the rate of increase of the energy is given by

$$\left.\begin{aligned} \mathrm{S}_j' = \Sigma \int d(\text{vol.})_h \left(\mathrm{A}\frac{d(u-\mathrm{U})}{dt} + \mathrm{B}\frac{d(v-\mathrm{V})}{dt} + \mathrm{C}\frac{d(w-\mathrm{W})}{dt}\right) \\ + \Sigma \int d\,(\text{surface})_{hk}\, \mathrm{S}_{hk} = \mathrm{J}\,(\text{vol.}) + \mathrm{J}\,(\text{surface}) \end{aligned}\right\} \quad (52)$$

where the Σ implies that more than one medium may come into consideration, and the integrals are to extend over the whole volume of each separate medium and all the interfaces between the media, these being indicated by J (vol.) and J (surf.) respectively.

Forms are then found for A, B, C which make J (vol.) a complete differential coefficient with respect to the time, and at the same time lead to linear equations of motion which admit of solution in the form $u = \Sigma \mathrm{A} e^{(lx+my+nz+ct)}$. Four possible forms are found, which are given below.

$$\left.\begin{aligned} &(1) \quad -\mathrm{A}_1 = n_1(u-\mathrm{U}) + o_3(v-\mathrm{V}) + o_2(w-\mathrm{W}) \\ &(2) \quad \mathrm{A}_2 = p_3\frac{d(v-\mathrm{V})}{dt} - p_2\frac{d(w-\mathrm{W})}{dt} \\ &(3) \quad -\mathrm{A}_3 = r_1\frac{d^2(u-\mathrm{U})}{dt^2} + s_3\frac{d^2(v-\mathrm{V})}{dt^2} + s_2\frac{d^2(w-\mathrm{W})}{dt^2} \\ &(4) \quad \mathrm{A}_4 = q_3\frac{d^3(v-\mathrm{V})}{dt^3} - q_2\frac{d^3(w-\mathrm{W})}{dt^3} \end{aligned}\right\} \quad . \quad (53)$$

It will be noticed that (1) gives us Helmholtz's theory; (3) gives us Ketteler's in the modified form I have suggested; for an isotropic medium it is shown that the coefficients o and s vanish. Lommel's form is not included in the above; it is therefore, we see, inconsistent with the conservation of energy in the medium.

But there are other terms in the volume integral J (vol.) which will, when combined with suitable terms in the surface integral J (surf.), make the whole up to a differential coefficient of the time.

These terms are given by

$$-\mathrm{A} = \frac{d\mathrm{A}_x}{dx} + \frac{d\mathrm{A}_y}{dy} + \frac{d\mathrm{A}_z}{dz} \quad . \quad . \quad . \quad . \quad (54)$$

etc., and lead to terms in the volume integral

$$\int d\,(\text{vol.})\left[\mathrm{A}_x \frac{d^2(u-\mathrm{U})}{dtdx} + \mathrm{A}_y \frac{d^2(u-\mathrm{U})}{dtdy} + \mathrm{A}_z \frac{d^2(u-\mathrm{U})}{dtdz} + \ldots\right]$$
$$= \frac{df'}{dt} \text{ (let us suppose)} \quad . \quad (55)$$

Then f' is a function of $\frac{d(u-\mathrm{U})}{dx}$, etc., and four possible forms are found for A_x, etc., viz. putting χ, etc., for the differential coefficients $\frac{d(u-\mathrm{U})}{dx}$, etc.

(5) f'_5, a homogeneous function of $\chi_1 \quad . \quad . \quad . \quad \chi_9$

$$-(\mathrm{A}_x)_5 = \frac{df'_5}{d\chi_1}, \text{ etc.}$$

$$\text{Thus } -\mathrm{A}_x = \Sigma i n_{1i}\,\chi, \text{ etc.,}$$

$$\text{with } n_{ij} = n_{ji}.$$

(6) $$-\mathrm{A}_x = \Sigma p_{1i} \frac{d\chi_i}{dt}, \text{ etc.,}$$

$$\text{with the conditions } p_{ii} = 0,$$

$$p_{ij} = -p_{ji},$$

$$\text{giving } f'_6 = \text{constant}.$$

(7) $$-\mathrm{A}_x = \Sigma r_{1i} \frac{d^2\chi_i}{dt^2},$$

$$\text{with } r_{ij} = r_{ji},$$

$$\text{and } -2f'_7 = \Sigma\Sigma r_{ij} \frac{d\chi_i}{dt}\frac{d\chi_j}{dt}.$$

(8) $$-\mathrm{A}_x = \Sigma q_{1i} \frac{d^3\chi}{dt^3},$$

$$\text{with } q_{ii} = 0, \quad q_{ij} = -q_{ji},$$

$$\text{and } -f'_8 = \Sigma\Sigma q_{ij}\left(\frac{d^2\chi_i}{dt^2}\frac{d\chi_j}{dt} - \frac{d^2\chi_j}{dt^2}\frac{d\chi_i}{dt}\right).$$

We have thus eight possible forms of values for A, etc., all or any of which may occur in the equations. In the equations for the ether, U, V, W, being very small compared with u, v, w, are omitted.

An isotropic body is one in which no one direction differs in its properties from any other. For such a body it is supposed that the forces defined by 2, 4, 6, and 8 above do not exist, and a, a' being the coefficients in $-2f'_5$ and $-2f'_7$ respectively, it is shown that the equation for plane waves travelling parallel to z is—

$$(m+r)\frac{d^2u}{dt^2} = (e+a)\frac{d^2u}{dz^2} + a'\frac{d^4u}{dz^2dt^2} - nu \quad . \quad . \quad (56)$$

and hence,

$$\frac{1}{N^2} = \frac{\frac{m(e+a)}{e} - \frac{4a'\pi^2}{\lambda^2}}{m + r - \frac{n\lambda^2 m}{4e\pi^2}},$$

λ being the wave length in air and N the refractive index.

The complete value for A is—

$$A = -r\frac{d^2(u-U)}{dt^2} + a\frac{d^2(u-U)}{dz^2} + a'\frac{d^4(u-U)}{dz^2dt^2} - n(u-U) \quad . (57)$$

and in the above equation (56) U has been treated as small compared with u.

We see that the first and last terms are those given by the theories of Ketteler and Helmholtz respectively; Voigt's more general theory includes them as particular cases. The first and third terms occur in the theory developed by Boussinesq, which is also included in Voigt's.

In a further paper, in reply to some criticisms of Lommel, who argues that a wave propagated through the molecules of the medium must be a sound-wave, and that therefore the matter motion which affects the transmission of light must be *intra*-molecular not *inter*-molecular, Voigt shows,[1] by taking the matter motion into account, that the velocity of wave propagation in a medium constituted as supposed will be given by a quadratic equation. One root of this quadratic will be comparable with the velocity of light in this medium, the other with that of sound; while the ratio of the energy of the matter to that of the ether in the light-motion is the reciprocal of the same ratio in the sound-motion.

Voigt's theory applies only to perfectly transparent media, and its aim is to show that the optical properties of all such media can be explained on an elastic solid theory by considering the mutual reactions of two mutually interpenetrating elastic media. The author does not touch the problem of absorption, because for that purpose we require to deal with the molecular motion to which, in his opinion, heat effects are due, and these lie outside the domain of elastic solid theories. He does, however, deal with double refraction, circular and elliptic polarisation, and the various problems connected with reflexion and refraction. Most of these have been treated of also by Lommel and Ketteler.

Chapter II.—Double Refraction.

We will consider first the problem of double refraction. All three explain it in a similar manner. Within a crystal the action of the matter particles on the ether will depend on the direction of vibration, and some or other of the constants of the theory will be functions of this direction. It is assumed that the ether remains isotropic, and that there are three axes of symmetry, which are taken as those of the co-ordinates.

§ 1. Lommel[2] in his theory treats the constant we have denoted by a^2 as a function of the direction. β^2, which determines the action between ether and matter, and γ^2, on which the frictional effects depend,

[1] Voigt, 'Zur Theorie des Lichtes,' *Wied. Ann.* t. xx. p. 144.
[2] Lommel, 'Theorie der Doppelbrechung,' *Wied. Ann.* t. iv. p. 55.

are left invariable, so that the ether equations remain unaltered, and the matter equations become—

$$\mu\frac{d^2\mathrm{U}}{dt^2} = -\beta^2\frac{d}{dt}(\mathrm{U}-u) - a_1{}^2\mathrm{U} - \gamma^2\frac{d\mathrm{U}}{dt} \quad . \quad . \quad . \quad (58)$$

and similar equations with $a_2{}^2$ and $a_3{}^2$. It has been shown by him that for a transparent medium the velocity is given by $1/r$, where r is a radius, drawn in the direction of displacement of the surface—

$$(x^2+y^2+z^2-1)\left(\frac{x^2}{\mathrm{N}_1{}^2-1}+\frac{y^2}{\mathrm{N}_2{}^2-1}+\frac{z^2}{\mathrm{N}_3{}^2-1}\right)=x^2+y^2+z^2 \quad (59)$$

and the directions of vibration are the axes of a section of this surface by the wave.

These results are at variance with experiment, which requires that the wave surface should be that of Fresnel, and no reason is assigned in the paper for making a^2 rather than β^2 or γ^2 a function of the direction.

Circular polarisation and the rotation of the plane of polarisation [1] are also treated of by introducing into the equation for U the term $-2\mu\delta\cos\alpha\frac{d\mathrm{V}}{dt}$, and into the equation for V, $2\mu\delta\cos\alpha\frac{d\mathrm{U}}{dt}$, where δ depends on the strength of the magnetic force, and α is the angle between its direction and the axis of z.

From this it follows that the rotation is proportional to

$$\frac{a}{\lambda^2}+\frac{b}{\lambda^4}+ \quad . \quad . \quad . \quad .$$

and the results of calculation agree fairly well with Verdet's experiments.[2]

For the rotation of sugar terms of the same kind, but without the $\cos\alpha$, are introduced.

It has been shown long since, by Airy,[3] Neumann, and MacCullagh, that such terms in the equations would lead to results in fair agreement with experiment, and Lommel does not attempt any other justification of their existence than that the results they lead to are in agreement with experiment. Similar remarks apply to his paper on the properties of quartz,[4] in which the same terms are added to the differential equations already found for a crystalline media. The two waves travelling in any given direction inclined at an angle θ to the axis are elliptically polarised. The elliptic paths of the particles are similar; their ratio is given by—

$$\gamma=\frac{d_0\cos^2\theta}{b\sin^2\theta+\{b^2\sin^4\theta+d_0{}^2\cos^4\theta\}^{\frac{1}{2}}} \quad . \quad . \quad (60)$$

and the difference of phase between the two by

$$d^2=b^2\sin^4\theta+d_0{}^2\cos^4\theta \quad . \quad . \quad . \quad (61)$$

where b and d_0 are functions of the refractive indices and wave lengths. The axial rotation is given by—

$$\Omega=\mathrm{C}\frac{(\mathrm{N}^2-1)^2}{\mathrm{N}\lambda^2} \quad . \quad . \quad . \quad . \quad (62)$$

[1] Lommel, 'Theorie der Dehnung der Polarisationsebene,' *Wied. Ann.* t. xiv. p. 523.
[2] Verdet, *Ann. de Chim.* (3), t. 69, p. 471.
[3] Airy, *Phil. Mag.* June, 1846; Neumann, *Die magnetischen Dehnungen*, Halle, 1863; McCullagh, *Roy. Irish Trans.*
[4] Lommel, 'Theorie der elliptischen Doppelbrechung,' *Wied. Ann.* t. xv. p. 378.

These results are all in close agreement with experiment.

In another paper [1] this formula is carried to a higher degree of approximation, and reduces to $\Omega = \frac{a(N^2-1)^2}{\lambda^2}$. This agrees well with the measurements of Soret and Sarasin, between the wave lengths 7604 and 2143.

§ 2. Ketteler's contributions to the theory of double refraction have been very numerous. Most of the papers already mentioned,[2] contain something on the subject. The theory given in the first of the papers mentioned is in its fundamental principles in close accordance with that developed by Lord Rayleigh in 1871, though the equations given on p. 95, following Von Lang, as representing the motion in a crystalline elastic solid are incorrect. In it a distinction is drawn between the displacement normal to the ray, which leads, it is said, to equations of the form—

$$(m+m_x)\frac{d^2u}{dt^2}+\frac{dp}{dx}=a^2\nabla^2 u \quad . \quad . \quad . \quad (63)$$

and those in the wave front, for which the equations are—

$$(m+m_x)\left(\frac{d^2u}{dt^2}+\frac{dp}{dx}\right)=a^2\nabla^2 u \quad . \quad . \quad . \quad (64)$$

The arguments by which the second equation is deduced from the first are somewhat obscure; they are, however, further developed in a later paper.[3] The ray direction is defined as that in which the energy of the vibration is propagated, and the direction of vibration is normal to this.

The fundamental equations of this theory have already been given.[4] They are, in their final form,[5]

$$\left.\begin{aligned} m\frac{d^2u}{dt^2}-m'C_0\frac{d^2U}{dt^2}&=e\nabla^2u+\beta m'U \\ m'C_0\frac{d^2u}{dt^2}+m'\frac{d^2U}{dt^2}&=-\left(\kappa U+\gamma\frac{dU}{dt}\right) \end{aligned}\right\} \quad . \quad . \quad (65)$$

where the constants C_0, β, κ and γ may all be functions of the direction. It is shown in the paper ('Optische Controversen') now before us that the conditions of incompressibility require that C_0, κ and γ should be constant, so that the theory turns entirely on the variability with the direction of β, or rather of C', which is connected with C_0 by the equation—

$$C'=\beta\frac{r^2}{4\pi^2}-C_0 \quad . \quad . \quad . \quad . \quad . \quad (66)$$

This is fatal to the groundwork of the theory, for in its form in the 'Optische Controversen' it is assumed that C' and C_0 are unconnected. The paper 'Zur Dispersionstheorie' starts without the term in β, arriving at the equation $C'+C_0=0$, and then (p. 203) inserts the β ' in

[1] 'Lommel, 'Das Gesetz der Rotationsdispersion,' *Wied. Ann.* t. xx. p. 578.

[2] See p. 179; and also Ketteler, 'Zur Theorie der Doppelbrechung,' *Wied. Ann.* t. vii. p. 94; 'Theorie der absorbirenden Anisotropen-Mittel,' *Monatsber. der Königl. Akad. der Wiss. zu Berlin*, November 13, 1879.

[3] Ketteler, 'Optische Controversen II.' *Wied. Ann.* t. xviii. p. 631.

[4] See p. 228.

[5] Ketteler, 'Zur Dispersionstheorie des Lichtes,' *Wied. Ann.* t. xxi. p. 199.

order to explain experimental results.' Introducing the term C′, as defined above, the equations become—

$$\left.\begin{aligned} m\frac{d^2u}{dt^2} - m'C'_x\frac{d^2U}{dt^2} &= e\nabla^2 u \\ m'C_0\frac{d^2u}{dt^2} + m'\frac{d^2U}{dt^2} &= -\left(\kappa U + \gamma\frac{dU}{dt}\right) \end{aligned}\right\} \quad . \quad . \quad (67)$$

These equations will not lead to satisfactory results.

Circular[1] and elliptic polarisation are also treated of by Ketteler, and are explained on the supposition that terms of the form $-\left(\mathfrak{f}V + \mathfrak{g}\frac{dV}{dt}\right)$ come into the equation for U, and terms $+\left(\mathfrak{f}U + \mathfrak{g}\frac{dU}{dt}\right)$ into that for V. The rotation in a magnetic medium is given by $\Omega = \pi f\frac{(N^2-1)}{N\lambda^2}$, N being the refractive index, while the value of N in a crystal like quartz may be found from the formula—

$$\begin{aligned} N^2 - 1 = (N_1{}^2 - 1)(1 + \cos^2\theta) + (N_2{}^2 - 1)\sin^2\theta \pm [(N_1{}^2 - N_2{}^2)\sin^4\theta \\ + 4k^2\lambda^2\cos^2\theta(N_1{}^2 - 1)(N_1{}^2\cos^2\theta + N_2{}^2\sin^2\theta - 1)]^{\frac{1}{2}} \quad . \quad . \quad (68) \end{aligned}$$

N_1 and N_2 being the refractive indices at right angles to the axis, and k, a constant on which the rotatory power depends. For ordinary active media the law of the rotation is

$$\Omega = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4} +, \text{etc.} \quad . \quad . \quad . \quad (69)$$

It will be noticed that in the theories of both Lommel and Ketteler the rotatory terms are introduced into the equations of the matter particles, and affect the ether only indirectly through the values of u, v, and w.

§ 3. Voigt's work[2] embraces double refraction and circular polarisation. The existence of three principal axes is assumed, and for these the coefficients o and s in the values of f_1 and f_3* of equations (53) vanish. The values of f_5 and f_7 are written down with coefficients a_1, a_2, etc., and a_1', a_2', etc., respectively, and finally the equation of motion for u is obtained in the form—

$$\begin{aligned} (m + r_1)\frac{d^2u}{dt^2} = e\nabla^2 u + \frac{dp}{dx} - n_1 u + a_1\frac{d^2u}{dx^2} + b_{12}\frac{d^2u}{dy^2} + b_{13}\frac{d^2u}{dz^2} \\ + (c_3 + b_3)\frac{d^2v}{dxdy} + (c_2 + b_2)\frac{d^2}{dxdz} + \frac{d^2}{dt^2}\,[\text{similar terms with } a_1', \text{ etc.}] \quad (70) \end{aligned}$$

It will be seen that there are enough coefficients here to give any imaginable theory of double refraction.

Put $m + r_1 = m_1$, etc. Then the equations may be written

$$\left(m_1\frac{d^2}{dt^2} + n_1\right)u = A_1\frac{d^2u}{dx^2} + B_{12}\frac{d^2u}{dy^2} + B_{13}\frac{d^2u}{dz^2} + \frac{dP}{dx} \quad . \quad . \quad (71)$$

[1] Ketteler, 'Theorie der circularen und elliptischen polarisirenden Mittel,' *Wied. Ann.* t. xvi. p. 86.

[2] 'Theorie des Lichtes für vollkommen durchsichtige Medien,' *Wied. Ann.* t. xix. p. 873.

* See p. 231.

Where $A_1 = A_1 + A_1' \frac{d^2}{dt^2}$, A_1 and A_1' being functions of a, b, c, etc., and P is a linear function of p and the differential coefficients $\frac{du}{dx}$, etc.

The equations in this form may be compared with Green's, which differ from them only in the facts that his coefficients of d^2u/dt^2, d^2y/dt^2, and d^2z/dt^2 are the same, and his other coefficients are independent of the time. Voigt's equations, in fact, include both Green's and those given by Lord Rayleigh.

Let τ be the period of vibration, and denote $m_1 - n_1\tau^2$ by T_1, etc.; then it is shown that if we assume the relation $\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} = 0$, in order to obtain Fresnel's wave surface at all the condition $T_1 = T_2 = T_3 = T$ is necessary.

These equations being satisfied, the other relations required to give Fresnel's construction on either assumption as to the connection between the plane of polarisation and the direction of vibration are those given by Green, with the addition that since in Voigt's coefficients the period is involved, and since Fresnel's construction holds for all wave lengths, each of Green's relations splits into two.

A difficulty as to the meaning of the constants leads Voigt to prefer Neumann and MacCullagh's theory as to the position of the plane of polarisation. To obtain Fresnel's original construction it is necessary to suppose B_{12} to be different from B_{21}, and this would imply that elastic reactions are brought into play by rotating an element of ether as a whole without dilatation; that, in the ordinary notation of elastic solids, T_{yz} is different from T_{zy}. If we treat this as out of the question, then B_{12} must be equal to B_{21}, and Fresnel's original construction for the plane of polarisation is impossible.

Circular polarisation is explained by the terms introduced by f_2, f_4, f_6, and f_8 of above,[1] but the terms to which f_4 and f_8 would give rise are omitted as not necessary to explain any known phenomena, and the equations in an isotropic medium become—

$$(m+r)\frac{d^2u}{dt^2} = (e+a)\frac{d^2u}{dz^2} + a'\frac{d^4u}{dz^2dt^2} - nu + p\frac{dv}{dt} + p\frac{p'd^3v}{dz^2dt} \quad . \quad (72)$$

etc.; the rotation produced by a thickness δ of the medium will be—

$$\Omega = \frac{\delta}{2\sqrt{(e+a)(m+r)}}\left(p - \frac{p'}{\tau^2\omega^2}\right)\left(1 + \frac{a'}{2(e+a)\tau^2}\right).$$

The same terms are then applied to a crystal, and the case of a uniaxial crystal such as quartz is worked out in full.

The equation to determine the velocity in a direction making an angle θ with the axis is found to be—

$$(\omega^2 - a^2)(\omega^2 - a^2\cos^2\theta - b^2\sin^2\theta) = \tau^2\left(p\omega^2 - \frac{p'^2}{\tau^2}\right) \quad . \quad (73)$$

a and b being the velocities at right angles to the axis.

This paper then gives a consistent account of the propagation of light in all known transparent bodies. We proceed to deal with the problem

[1] See p. 231.

of reflexion and refraction on this theory, and after that to make some general remarks on the whole.

Chapter III.—Reflexion and Refraction.

§ 1. Lommel, so far as I am aware, has not considered the problem of the reflexion and refraction of light on his theory. Ketteler, however, has discussed it in many of his papers.

In one of the earlier papers [1] the fundamental principles on which he intends to work are laid down. They are as follows:—

I. The conservation of energy.

II*a*. The continuity of the stress parallel to the surface of separation.

II*b*. The continuity of the component of the force on an element resolved normal to the surface.

III. The continuity of the displacement resolved along the surface.

The reasons given for II*b*. in place of the correct principle of the continuity of the stress normal to the surface are not very clearly stated.

No assumption, except such as is implied in I. and III. combined, is made as to the displacement normal to the surface.

The principles are then applied to the general problem, but in expressing them in symbols, except in the case of I., the motion of the matter is entirely neglected. Thus the stress considered in II. is only that arising from the action of the ether; the part which springs from the reaction of the matter is omitted from consideration. Again, in forming the equations connecting the amplitudes of the incident reflected and refracted rays, II*b*. is not employed.

Ketteler's work, then, in this paper is not really specially connected with his theory of the mutual reaction between the ether and matter. It is rather a modification of Fresnel and Green's work, for which there can be no justification assigned. The problem of metallic reflexion is discussed, and in a second part [2] of the same paper that of moving media. In the next paper on this subject [3] the correct principle of the continuity of the stress normal to the bounding surface is introduced in place of one of the other conditions, but it is supposed that the term involving the dilatation disappears in consequence of the incompressibility of the ether; in reality, as Green showed, the coefficient of that term is very large, and it must be retained to give correct results. Ketteler fails to see this, and hence concludes that the retention of Green's longitudinal wave is unnecessary. He then considers, as Green had done, the problem of total reflexion; and, through not taking into account the continuity of the displacement normal to the surface, appears to be able to do without the longitudinal waves. The motion of the matter particles does not come into consideration.

Another series of surface conditions are given in the next paper on the subject,[4] and the matter particles being treated merely as a sort of

[1] Ketteler, 'Beiträge zur einer endgültigen Feststellung der Schwingungsebene des polarisirten Lichtes,' *Wied. Ann.* t. i. p. 206.

[2] Ketteler, *Wied. Ann.* t. i. p. 556.

[3] Ketteler, 'Zur Theorie der longitudinalen elliptischen Schwingungen im incompressiblen Ether,' *Wied. Ann.* t. iii. pp. 83, 284. See also *Theoretische Optik*, p. 130.

[4] Ketteler, 'Ueber den Uebergang des Lichtes zwischen absorbirenden isotropen und anisotropen Mitteln und über die Mechanik der Schwingungen in denselben,' *Wied. Ann.* t. vii. p. 107.

ballast, their motions do not come into the surface conditions. While, finally,[1] Ketteler adopts the principle enunciated by Kirchhoff,[2] and already discussed above,[3] viz. that no work is done by the action of the stresses in the media on the bounding surface. In applying this principle he equates to zero, as Kirchhoff has done, the terms involving the dilatation; and this, as has been already shown, leads to MacCullagh's formulæ on his assumption as to the equality of the density in the two media, and to Fresnel's if the rigidity be assumed equal in the two. The theory is applied to metallic reflexion and total reflexion within crystals in another paper.[4] Thus, while Ketteler's first theory[5] was in reality Green's erroneously altered, this second theory is that given by Kirchhoff in the paper already quoted. Neither of them really seems to me to involve the distinctive features of Ketteler's theory of the propagation of light.

§ 2. Voigt's theory is contained in the paper already referred to.[6]

The conditions assumed are:—

I. The displacement of the parallel to the surface ether is continuous in the two media.

II. The displacement normal to the surface multiplied by the density is continuous.[7]

III. Kirchhoff's principle—viz. that the work done by the stresses on the interface of the two media vanishes.

In evaluating the expression for this work Voigt takes into account correctly the terms arising from the action of the matter on the ether. The displacements which come into the equations expressing the first two conditions are strictly displacements of the ether relatively to the matter, but since it is assumed that the motion of the matter particles is very small compared with that of the ether, the absolute displacements of the ether particles are introduced.

The results arrived at, however, are hardly satisfactory. In the first place, in evaluating the expression for the work done on the surface, the term involving the dilatation is omitted. Voigt has taken it into account in his equations of motion; his reason for omitting it here is not given. He thus avoids the question of the so-called longitudinal vibrations.

He then considers the case of vibrations at right angles to the plane of incidence, and arrives at the formulæ—

$$\left.\begin{aligned} &E_s + R_s = D_s \\ &(m_1 + r_1 - n_1\tau^2)\,(E_s - R_s)\sin\phi_1\cos\phi_1 \\ &\qquad = (m_2 + r_2 - n_2\tau^2)\,D_s\sin\phi_2\cos\phi_2 \end{aligned}\right\} \quad . \quad . \quad (74)$$

E, R, and D being the amplitudes of the incident reflected and refracted waves.

[1] 'Ketteler, 'Optische Controversen II.' *Wied. Ann.* t. xviii. p. 632.
[2] Kirchhoff, *Abhandl. der Berl. Akad.* 1876, p. 57.
[3] See p. 193.
[4] Ketteler, 'Ueber Probleme welche die Neumann'sche Reflexionstheorie nicht lösen zu können scheint,' *Wied. Ann.* t. xxii. p. 204.
[5] See p. 162.
[6] Voigt, 'Theorie des Lichtes für vollkommen durchsichtige Medien,' *Wied. Ann.* t. xix. p. 873. See also Voigt, 'Ueber die Grundgleichungen der optischen Theorie des Herrn E. Ketteler,' *Wied. Ann.* t. xix. p. 691, especially p. 696 *seq.*
[7] See p. 186; also Cornu, *Ann. de Chim.* (4), t. xi. p. 283.

These become MacCullagh's and Neumann's formulæ on the assumption that

$$\left.\begin{aligned} m_1 + r_1 &= m_2 + r_2 \\ n_1 &= n_2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (75)$$

They become Fresnel's if

$$\left.\begin{aligned} e_1 + a_1 &= e_2 + a_2 \\ a'_1 &= a'_2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (76)$$

for these equations lead—remembering the value of the velocity—to the condition—

$$\frac{m_1 + r_1 - n_1 \tau^2}{m_2 + r_2 - n_2 \tau^2} = \frac{\sin^2 \phi_2}{\sin^2 \phi_1}.$$

For the vibrations in the plane of incidence the results of the first and second principles are inconsistent with that of the third. For the first and second give

$$\left.\begin{aligned} (\mathrm{E}_p + \mathrm{R}_p) \cos\phi_1 &= \mathrm{D}_p \cos\phi_2 \\ m_1(\mathrm{E}_p - \mathrm{R}_p) \sin\phi_1 &= m_2 \mathrm{D}_p \sin\phi_2 \end{aligned}\right\} \quad . \quad . \quad . \quad (77)$$

while the first and third give, instead of this second equation,

$$(m_1 + r_1 - n_1\tau^2)\ (\mathrm{E}_p - \mathrm{R}_p)\ \sin\phi_1 = (m_2 + r_2 - n_2\tau^2)\ \mathrm{D}_p\ \sin\phi_2\ . \quad (78)$$

They become consistent if we assume $m_1 = m_2$, and, adopting Neumann's hypothesis,

$$r_1 = r_2, \quad n_1 = n_2,$$

or, adopting Fresnel's,

$$e_1 + a_1 = e_2 + a_2, \quad a'_1 = a'_2.$$

In another paper[1] it is shown that Kirchhoff's principle, when applied to circularly polarising media, leads to an impossible result, and the principle is modified by the supposition that the work done is a function of the time only, and not zero.

The theory of ordinary absorbing media is developed[2] from the supposition that terms involving a loss of energy may come in through the mutual reaction of the ether and matter, and it is shown that these would lead to terms of the form $-b\dfrac{du}{dt} + c\nabla^2\dfrac{du}{dt}$ in the equation for u, which merely becomes, for waves travelling parallel to z,

$$\mathrm{M}_1 \frac{d^2u}{dt^2} = \mathrm{A}_1 \frac{d^2u}{dz^2} - b\frac{du}{dt} + c\frac{d^3u}{dz^2dt} \quad . \quad . \quad . \quad (79)$$

where

$$\left.\begin{aligned} \mathrm{M}_1 &= m_1 + r_1 - n_1\tau^2 \\ \mathrm{A}_1 &= e_1 + a_1 - \frac{a'_1}{\tau^2} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (80)$$

In considering the problem of reflexion in this case, Voigt assumes that the plane xy being the face of incidence, $\mathrm{M}w$ is continuous. The

[1] Voigt, 'Das G. Kirchhoff'sche Princip und die Theorie der Reflexion und Brechung an der Grenze circular-polarisender Medien,' *Wied. Ann.* t. xx. p. 522.

[2] Voigt, 'Theorie der absorbirenden isotropen Medien,' *Wied. Ann.* t. xxiii. p. 104.

principle laid down in the former paper[1] would require that this should be mw, not Mw, as he points out, remarking that the equation given is only true under certain restrictions, and, in fact, he shows that for vibrations in the plane of incidence the continuity of Mw is inconsistent with the energy equation, at least unless $b=0$. The energy equation gives—

$$M_1 w_1 = M_2 w_2 - b_2 \tau \frac{dw_2}{dt} \Big\} \quad . \quad . \quad . \quad (81)$$

and this form is assumed for the rest of the work.

Expressions are then found for the difference of phase between the reflected, refracted, and incident beams, and for their relative intensities, and these are compared with theory on the assumption that the constant b vanishes, and that $M_1 = M_2$. The results of the comparison are satisfactory; but this, however, can hardly be said for the principles from which they are deduced, while the difficulties we have already alluded to as to the negative value for the real part of the square of the refractive index remain in their full force.

Chapter IV.—Theory of Sir William Thomson. General Considerations.

§ 1. The lectures of Sir William Thomson delivered last year at Baltimore have developed a new interest in the theories now under consideration. After discussing at some length the elastic solid theory and throwing much light on it, and on the meaning of the twenty-one coefficients of Green's theory, he points out its unfitness to explain the phenomena, and then proceeds to work out the consequences of a special form of reaction between the ether and matter; this he illustrates in his own inimitable manner by his mechanical model of the ether within a transparent body. This mechanical model consists of a number of concentric hollow spheres. Each sphere is connected with the one within it by zigzag springs, and in the centre there is a solid mass connected also by springs with the shell next to it. The dimensions of these shells, which represent the matter molecules, are supposed to be small compared with the wave length. The interior molecule will have a number of periods of vibration depending on the number and nature of the spring connections, on its own mass, and on the masses of the shells. The springs are supposed to be massless. The shell molecules are distributed through the ether in very large numbers, and the outermost shell is connected with the ether.

It is further supposed that the forces arising from the springs are proportional to the relative displacements of the centres of the shells, and that the ether acts on the first shell with a force proportional to the relative displacement of that shell and the ether surrounding it, so that, if ξ be the ether displacement, x_1, x_2 those of the shells, $m_1/4\pi^2$, $m_2/4\pi^2$, etc. their masses, the equations of motion are,

$$\left.\begin{aligned} \frac{m_1}{4\pi^2}\frac{d^2x_1}{dt^2} &= C_1(\xi - x_1) - C_2(x_1 - x_2) \\ \frac{m_2}{4\pi^2}\frac{d^2x_2}{dt^2} &= C_2(x_1 - x_2) - C_3(x_2 - x_3) \end{aligned}\right\} \quad . \quad . \quad (82)$$

[1] Voigt, *Wied. Ann.* t. xix. p. 900. See above, p. 239.

etc. If we suppose the whole motion to be harmonic and of period τ, then the equations become

$$-\frac{m_1}{\tau^2}x_1 = C_1(\xi - x_1) - C_2(x_1 - x_2) \quad . \quad . \quad . \quad (83)$$

etc., from which the motion of the various shells can be determined. The system will represent Helmholtz's theory if we suppose the viscous terms in his expression to vanish, and consider only a single shell. The solution in the general case is carried further by putting

$$\left.\begin{aligned} a_i &= \frac{m_i}{\tau^2} - C_i - C_{i+1} \\ \text{and} \qquad u_i &= -\frac{C_i x_{i-1}}{x_i} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (84)$$

The equations may then be written—

$$\left.\begin{aligned} u_1 &= a_1 - \frac{C_2{}^2}{u_2} \\ u_2 &= a_2 - \frac{C_3{}^2}{u_3} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (85)$$

etc., whence we find u_1 as a continued fraction.

By differentiating these expressions with reference to τ^{-2}, and writing δ for $\frac{d}{d\tau^{-2}}$, we find—

$$\delta u_i = m_i + \left(\frac{C_{i+1}}{u_{i+1}}\right) m_{i+1} + \left(\frac{C_{i+1}C_{i+2}}{u_{i+1}u_{i+2}}\right)^2 m_{i+2} +, \text{ etc.} \quad . \quad . \quad (86)$$

Hence

$$\frac{du_i}{d\tau} = -\frac{2}{\tau^3}\frac{1}{x_i^2}\left\{m_i x_i^2 + m_{i+1}x^2_{i+1} + \quad . \quad . \quad . \quad . \right\} \quad . \quad . \quad (87)$$

Thus u decreases as τ increases, and if we start from τ, a small quantity, the u's are all large and positive; hence alternate shells are moving in opposite directions, and the motion of consecutive shells rapidly decreases.

As τ increases the u's decrease, and after a time one will become negative, passing through zero—it can be shown that u_1 is the first one thus to become negative. This gives the first critical case in the solution, for then x_1 is infinitely great compared with ξ, and the solution fails.

This equation can be put into the following more convenient form—

$$\frac{-x_1}{C_1\xi} = \frac{\tau^2}{m_1}\left\{\frac{\kappa_1{}^2 R_1}{\kappa_1{}^2 - \tau^2} + \frac{\kappa_2{}^2 R_2}{\kappa_2{}^2 - \tau^2} + . \quad . \quad . \quad . \right\} \quad . \quad . \quad (88)$$

where κ_1, κ_2, etc., are the critical values of τ, and R_1, R_2, etc., represent the ratio of the energy of the several shells to the whole energy of the system.

To apply this to the motion of the ether in a transparent body, let $m_1/4\pi^2$, etc., represent the whole mass contained within shell No. 1 per unit vol., let $\rho/4\pi^2$ be the density, and $e/4\pi^2$ the rigidity of the ether, and suppose the first shell, of mass m_1, to be connected by a spring to a massless

spherical lining, which is in rigid connection with the ether outside. Then the equation of motion is—

$$\rho \frac{d^2\xi}{dt^2} = e\frac{d^2\xi}{dx^2} + 4\pi^2 C_1 (x_1 - \xi) \quad . \quad . \quad . \quad (89)$$

Let the solution of this represent a train of waves of period τ and length λ, and let V be the wave velocity for the medium. Then

$$\frac{1}{V^2} = \frac{\tau^2}{\lambda^2} = \frac{1}{e}\left\{\rho - C_1\tau^2\left(1 - \frac{x_1}{\xi}\right)\right\}$$

$$= \frac{1}{e}\left[\rho - C_1\tau^2\left\{1 + \frac{C_1\tau^2}{m_1}\left(\frac{{}_1{}^2R_1}{\kappa_1{}^2 - \tau} + \frac{\kappa_2{}^2R_2}{\kappa_2{}^2 - \tau^2} + \ldots\right)\right\}\right] . \quad (90)$$

and if μ be the refractive index, since the velocity in free space is $\sqrt{e/\rho}$ we have, if we put $C_1\kappa_1{}^2R_1 = q_1 m_1$, etc.

$$\mu^2 = 1 + \frac{C_1}{\rho}\left\{q_1\kappa_1{}^2 - (1 - q_1)\tau^2\right.$$

$$\left. + q_1\kappa_1{}^2\left(\frac{\kappa_1{}^2}{\tau^2} + \frac{\kappa_1{}^4}{\tau^4} + \ldots\right) - \text{terms in } q_2, q_3\right\} \quad . \quad . \quad (91)$$

It follows from this that, q_1 must be very little less than unity if the formula, neglecting the terms in q_2, etc., is to apply to a transparent substance such as rock salt, which gives a value for μ between 1 and 2 for a range of the spectrum from the visible light to the longest waves emitted by a Leslie cube. The formula, we note, is the same in form as that given by Ketteler and Briot (see above, page 181), and Ketteler has shown that in some fairly transparent substances the coefficient $1 - q_1$ is appreciable. q_1 is essentially less than unity, so that the term in τ^2 comes in with a negative coefficient. The formula, then, will explain ordinary dispersion fairly if we put q_2, q_3, etc., all zero and take τ greater than κ_1.

The critical cases are then discussed from the form

$$\mu^2 = 1 + \frac{C_1\tau^2}{\rho}\left(-1 + \frac{q_1\tau^2}{\tau^2 - \kappa_1{}^2} - \frac{q_2\tau^2}{\kappa_2{}^2 - \tau^2} - \ldots\right\} \quad . \quad (92)$$

In this, τ is greater than κ_1 and less than κ_2 for ordinary refraction. As τ decreases down to κ_1, μ^2 passes through the value infinity and then becomes negative, we have greater and greater refraction, and then the waves cease to be transmitted and absorption takes place.

And here we are met with the question—What becomes of the energy thus absorbed? According to our equation the ratio x_1/ξ becomes infinite, and the solution as it stands fails to meet this difficulty. Helmholtz introduced the term $-\gamma^2 dU/dt$ into the motion of the first shell, and this, representing as it does a viscous consumption of energy by the matter molecules, is objected to by Sir Wm. Thomson. Helmholtz's solution given on p. 221 becomes identical with that at present under discussion if we put $\gamma = 0$; it is to meet this case in which $\tau = \kappa_1$ that the term in γ^2 is introduced, for if k represent the co-efficient of absorption on Helmholtz's theory, and we suppose γ to be small, then, with Thomson's notation,

$$k = K\frac{\gamma^2\tau^4}{(\tau^2 - \kappa_1{}^2)^2}$$

very approximately, K being a constant, and k may be very small except when τ is nearly equal to κ_1.

In order to account for the extreme transparency of a substance such as water, we must suppose k to be so exceedingly small that Sir William prefers to consider it as zero, and says: 'I believe that the first effect when light begins, of period exactly equal to κ_1, is that each sequence of waves throws in some energy into the molecule. That goes on until somehow or other the molecule gets uneasy. It takes in (owing to its great density relative to the ether) an enormous quantity of energy before it gets particularly uneasy. It then moves about, and begins to collide with its neighbours, perhaps, and will therefore give you heat in the gas if it be a gaseous molecule. It goes on colliding with other molecules, and in that way imparting its energy to them. This energy is carried away (as heat) by convection, perhaps. Each molecule set to vibrating in that way becomes a source of light, and we may thus explain the radiation of heat from the molecule after it has been got into it by sequences of waves of light.'

Helmholtz's equations are, of course, the more general, and apply to an absorption band as well as to the part of the spectrum for which the medium is transparent. It would seem that the term $-\gamma^2 d\text{U}/dt$ may rightly represent just the effect of that loss of energy in the form of heat due to the irregular collisions of which Sir William speaks, an effect which is only appreciable in the result when, owing to the coincidence of the periods, U tends to become large compared with u, or, in Thomson's notation, x_1 large compared with ξ, and in this case x_1 will not become infinite, for the amplitude will be multiplied by the factor e^{-kz}, and k being large, the limit of the product comes into consideration.

Such a system of ether with attached matter molecules is thus shown to account for the phenomena of dispersion. A serious difficulty, however, is encountered when we reach the problem of double refraction.

§ 2. For we may suppose, in order to account for it, that C_1 is a function of the direction, and that for two principal directions it has the values C_1 and C_1', while C_2 is a constant independent of the direction.

Then, with only one enclosed mass,

$$\mu^2 = 1 + \frac{C_1\tau^2}{\rho}\,\frac{\left(\frac{m_1}{\tau^2} - C_2\right)}{C_1 + C_2 - \frac{m_1}{\tau^2}}; \qquad \qquad (93)$$

and to give a dispersion formula resembling Cauchy's we must have m_1/τ^2 considerable compared with C_2, and C_1 large compared with either.

Hence, if μ' be a second principal index,

$$\mu'^2 = 1 + \frac{C_1'\tau^2}{\rho}\,\frac{\left(\frac{m_2}{\tau^2} - C_2\right)}{C_1' + C_2 - \frac{m_1}{\tau^2}},$$

and therefore

$$\mu^2 - \mu'^2 = -\frac{C_1 - C_1'}{\rho}\,\frac{\tau^2\left(C_2 - \frac{m_1}{\tau^2}\right)^2}{\left(C_1 + C_2 - \frac{m_1}{\tau^2}\right)\left(C_1' + C_2 - \frac{m_1}{\tau^2}\right)}. \qquad (94)$$

which, remembering the relative magnitudes of the quantities, and writing D and D′ for the approximate values of the denominators, becomes

$$\mu^2 - \mu'^2 = -\frac{C_1 - C_1'}{\rho DD'}\left(\frac{m_1}{\tau}\right)^2$$

so that the difference between the squares of the refractive indices will be inversely proportional to the squares of the wave length, and this is quite contrary to experiment. The question as to whether the theory here suggested would lead to Fresnel's construction is not considered.

In a later lecture Sir William returns again to the question of what becomes of the energy absorbed by the molecules, and of the nature of the ether. As to the latter he adopts Stokes's view, that the medium may be perfectly elastic for the small disturbances of a light-wave, executed, as they are, in the twenty-million-millionth of a second, and yet be a perfect fluid in respect of forces which act, as may be supposed in the kinetic theory of gases, for the one-millionth of a second. Now, the numerical calculations of Professor Morley, undertaken at Sir William's suggestion, show that the energy given to a system such as described tends to become absorbed by the vibrations of lower modes, so that the original energy appears as vibrations in which the period may be the millionth of a second instead of, perhaps, the twenty-million-millionth, and this energy shows itself in the motions which we deal with in the kinetic theory of gases, rapid it may be in themselves, but slow compared with the light-vibrations.

§ 3. Metallic reflexion and the quasi-metallic reflexion of such substances as give anomalous dispersion are dealt with, and it is shown that the phenomena are such as would be produced by making μ^2, a negative quantity, and this is given by values of τ a little below the critical period.

Thus the molecular explanation of the great reflecting power of silver is that the highest mode of vibration of the molecules with which silver loads the ether is graver than the mode of the gravest light or radiant heat which has ever been reflected from silver; and if, again, for certain modes μ^2 is not negative, but less than unity, it shows that, conformably with the experiments of Quincke on gold leaves, we should expect light to travel through the medium faster than through air. This forms a marked and most important distinction between this theory and others which have been given to explain metallic reflexion. For the other theories the metallic effects arise from the importance of the viscous terms of the form $-\gamma du/dt$.

In an appendix Sir William works out the problem of reflexion and refraction, following Green and Lord Rayleigh so far as ordinary transparent media are concerned. He then transforms Green's formulæ for vibrations in the plane of incidence to the case in which μ^2 is a real negative quantity, and arrives at formulæ expressing, on a strict elastic solid theory, the intensity and change of phase in a wave reflected from metal.

According to this solution we have, if $\nu^2 = -\mu^2$ so that ν^2 is positive, the values of Φ and Ψ given by—

$$\left.\begin{aligned}
\Psi &= -\nu^2 \cos(ax+by+\omega t) + \tan\theta \frac{(\nu^2+1)^2}{\nu^2-1} \sin(ax+by+\omega t) \\
\Psi_1 &= -\nu^2 \cos(ax+by+\omega t) - \tan\theta \frac{(\nu^2+1)^2}{\nu^2-1} \sin(+ax+by+\omega t) \\
\Phi &= \frac{\nu^2(\nu^2+1)}{\nu^2-1} \epsilon^{-bx} \sin(by+\omega t) \\
\Psi' &= 2\epsilon^{bx} \cos(by+\omega t) \\
\Phi' &= -\frac{(\nu^2+1)}{\nu^2-1} \epsilon^{bx} \sin(by+\omega t)
\end{aligned}\right\} . \quad (95)$$

These are simplified if we put—

$$\left.\begin{aligned} h^2 &= \{(\nu^2+1)\,b^2+\nu^2a^2\}\left[\frac{h}{a}+\tan\theta\,\frac{(\nu^2+1)^2}{\nu^2-1}\right]\nu^2=\tan f \\ \mathrm{S} &= \nu^2\sec f \end{aligned}\right\} \quad . \quad (96)$$

and the displacements in the transparent medium are then, for the incident wave,

$$-\frac{2\pi}{\lambda}\,\mathrm{S}\,\sin\,(ax+by+\omega t+f),$$

and for the reflected,

$$\frac{2\pi}{\lambda}\,\mathrm{S}\sin\,(-ax+by+\omega t-f).$$

In this case the rigidities in the two media are supposed to be equal. Sir William has also worked out the problem in the case in which the rigidities are not equal, in the hopes that by this assumption combined with variations in the density—or rather effective density—the variations from Green's formulæ in the case of light polarised at right angles to the plane of incidence may be accounted for. He finds, however, that any difference of rigidity which might, combined with a difference of density, be sufficient to reconcile Green's theory with experiment would cause the proportion of light reflected at normal incidence to be greater than $\{(\mu-1)/(\mu+1)\}^2$, and this value, given by Green's theory, agrees closely with Rood's experiments. We are thus driven back to Lord Rayleigh's case of equal rigidities in the two media. For metals, then, we are to have the rigidities equal, and the value of μ^2 decreasing from $-\infty$ when $\tau=\kappa_1$ to zero when $\tau=\kappa_1/\mathrm{N}$, N being some large numerical quantity, and then again augmenting from zero to unity as τ decreases from κ_1/N to 0.

The dynamics give no foundation to a theory such as Cauchy's, in which μ^2 is a complex quantity. For light polarised in the plane of incidence we have, if n and n' be the rigidities, and

$$\left.\begin{aligned} r &= n'/n, \\ \text{and} \qquad \tan e &= r\{\nu^2\sec^2\theta+\tan^2\theta\}^{\frac{1}{2}} \end{aligned}\right\} \quad . \quad . \quad . \quad (97)$$

$$\left.\begin{aligned} \mathrm{R} &= \tfrac{1}{2}\{1+r^2(\nu^2\sec^2\theta+\tan^2\theta)\} \\ \zeta &= \mathrm{R}\cos\,(ax+by+\omega t-e) \\ \zeta &= \mathrm{R}\cos\,(-ax+by+\omega t+e) \end{aligned}\right\} \quad . \quad . \quad . \quad (98)$$

for the incident and reflected wave; and for the refracted wave,

$$\zeta=\varepsilon^{\frac{2\pi n}{\lambda}x\,(\nu^2+\sin^2\theta)^{\frac{1}{2}}}\cos\,(by+\omega t) \quad . \quad . \quad . \quad (99)$$

According to these formulæ the reflexion is total from a metal surface at all angles of incidence. Sir John Conroy has recently shown that the loss is exceedingly small. If light be polarised in any plane, then the vibration in the plane of incidence is retarded relatively to that at right angles to that plane by the amount $2f+2e-\pi$. If we suppose ν and $r\nu$ to be both very large numerics, this retardation becomes—

$$2\left\{\tan^{-1}\left(\frac{\sec\theta}{r\nu}+\ \tan\ \theta\right)-\tan^{-1}\left(\frac{\cos\theta}{r\nu}\right)\right\},$$

and from the observations which have been made on the value of the principal incidence, for which the retardation is $\frac{1}{2}\pi$, we can find a value for $r\nu$. For silver Sir J. Conroy's observations give $(r\nu)^{-1} = 3{\cdot}65$.

And here we are met with a great difficulty. Experiments show that there is very little chromatic effect about metallic reflexion. Thus, since the value of the principal incidence depends mainly on $r\nu$, this quantity must be independent of the period. Now $\nu^2 + 1$ is approximately proportional to τ^2 when τ is small compared with κ_1, and so this result requires that r, which is proportional to the effective rigidity, should also vary in a certain definite manner, and it is difficult to see how the theory is to give this.

The theory is then applied to the case of a thin metal plate, and leads to the fact that the phase of both components is accelerated by the transmission. The accelerations for the two cases are given by—

$$\delta \cos\theta + \left(\frac{e}{\pi} - \frac{1}{4}\right)\lambda, \text{ vibrations normal to the plane of incidence,}$$

$$\delta \cos\theta + \left(\frac{1}{4} - \frac{f}{\pi}\right)\lambda, \text{ vibrations in the plane of incidence,}$$

when δ is the thickness of the plate, and e and f are found in the same manner as above.

This acceleration was discovered by Quincke, but the details of his results do not agree well with the formulæ. The formulæ are consistent with Kerr's discovery of the rotation of the plane of polarisation by reflexion from an iron plate when magnetised, but not with Kundt's result that transmission through a thin plate of iron in a magnetic field produces a very large rotation of the plane of polarisation.

In a final appendix an account is given of a gyrostatic molecule, the properties of which would give to the medium the heliacal effects seen in sugar and other active solutions. The molecule consists of a spherical shell in which are imbedded two gyrostats having a common axis, which initially is a diameter of the shell. One end of each axis is connected with the shell by a ball-and-socket joint, while the second extremities of each are connected together at the centre of the shell by a second ball-and-socket joint.

§ 4. Having thus given an account of the various theories proposed based in some way on the mutual reaction between the ether and matter, it remains to compare and contrast them.

The theories of Boussinesq and Voigt have much in common, and neither of the two as they stand applies to the case of bodies showing strong absorption, for the matter motion is entirely neglected. The theories of Sellmeyer, Helmholtz, and Thomson come under one head in that they all make the mutual reaction to depend on the relative displacement of the matter and ether.

Lommel's theory seems to me untenable: in its original form it contradicts the third law of motion, and if modified so as to be consistent with that, it leads to impossible laws for the relation between refraction and absorption; besides this, his theory of double refraction does not lead to Fresnel's wave surface, and there seems no reason why the coefficient a^2, which occurs only in the equation of motion of the matter, should be the one to be treated as a function of the direction. The laws of circular polarisation and of the double refraction in quartz, to which the theory leads, and which seem to agree with experiment, may be obtained

with sufficient approximation to fit the experiments from other theories; and, indeed, the fact that the wave surface in quartz does not become a sphere and a spheroid when the heliacal terms are neglected is fatal.

With regard to Ketteler's theory in the form finally given to it by its author,[1] it seems to me to have no possible mechanical basis. With the interpretation which he gives of the constants involved, his equations appear to contradict Newton's third law as effectually as do Lommel's, while, so far as the problem of reflexion and refraction is concerned, I cannot recognise the validity of Kirchhoff's principle as it is applied by Ketteler. At the same time I think that the suggestion of Ketteler—to which, however, he himself takes objection—already mentioned, leads to results which, so far as dispersion is concerned, agree closely with experiment.

We may with advantage compare the dispersion formula which it gives with that which comes from the theories of Helmholtz and Thomson. If we neglect the terms depending on viscous action, we have, according to Helmholtz, for μ, the refractive index,

$$\mu^2 = 1 - \frac{B\lambda^2}{\rho\lambda_1{}^2} + \Sigma\frac{B^2}{\rho m_1}\left\{\frac{\dfrac{\lambda^4}{\lambda_1{}^4}}{\dfrac{\lambda^2}{\lambda_0{}^2} - 1}\right\} \quad . \quad . \quad . \quad (100)$$

while, according to the modified form of Ketteler,

$$\mu^2 = \mu^2_\infty \left[1 + \Sigma\left\{\frac{D}{\dfrac{\lambda^2}{\lambda_0{}^2} - 1}\right\}\right] \quad . \quad . \quad . \quad (101)$$

Ketteler's equations come from Thomson's or Helmholtz's by writing for C_1 the quantity $-4\pi^2 C_1/\tau^2$, or for β^2 in Helmholtz's notation $-n^2\beta^2$. We may write Ketteler's equation in the form of a series thus—

$$\mu^2 = \mu^2_\infty \left[1 + \Sigma D\frac{\lambda_0{}^2}{\lambda^2}\left(1 - \frac{\lambda_0{}^2}{\lambda^2}\right)^{-1}\right]$$

$$= \mu^2_\infty \left[1 + \Sigma D\left\{\frac{\lambda_0{}^2}{\lambda^2} + \frac{\lambda_0{}^4}{\lambda^4} + \quad . \quad . \quad . \quad . \right\}\right] \quad . \quad (102)$$

two terms of which will give us Cauchy's series with three constants.

This modification leads also to an escape from one of the difficulties suggested by Sir William as to the explanation of double refraction.

For his general expression for μ^2 will become, if we write for C_1 the value $-4\pi^2 C_1/\tau^2$,

$$\mu^2 = 1 + \frac{4\pi^2 C_1}{\rho}\left\{1 - \frac{4\pi^2 C_1}{m_1}\left(\frac{\kappa_1{}^2 R_1}{\kappa_1{}^2 - \tau^2} + \quad . \quad . \quad . \quad . \right)\right\} \quad . \quad (103)$$

If we neglect for a moment the terms on which the dispersion depends, as being small compared with the term $4\pi^2 C_1/\rho$, which gives rise in the first instance to refraction, we get that

$$\mu^2 - \mu'^2 = \frac{4\pi^2(C_1 - C_1')}{\rho} \quad . \quad . \quad . \quad (104)$$

and there will be double refraction independently of the period.

[1] Ketteler, 'Zur Dispersionstheorie des Lichtes,' *Wied. Ann.* t. xxi. p. 199.

It is another question, and one which we shall discuss shortly, whether the double refraction thus produced will give rise to Fresnel's wave surface.

There seem, then, to be reasons why we should expect terms such as Ketteler has suggested in our equations—terms which will make the mutual reaction of the ether and the first matter shell depend rather upon their relative accelerations than upon their relative displacements. It is not so easy to suggest a mechanical connection between the ether and matter which would give rise to this force, but at the same time there is, I think, no mechanical reason to be urged against it.

Voigt's theory of wave propagation is in one way more comprehensive than those we have considered, while in another it is less so. It is more comprehensive in that it includes both sets of terms with some others in the expression for the mutual reaction; it is less so in that it treats the ratio U/u as a small quantity which may be neglected. This same remark applies to Boussinesq, whose work in one sense is more general that Voigt's, in that he considers the effect of the attached molecules on the condensational or pressural wave.

The presence of these molecules has been shown in Boussinesq's paper to alter the effective compressibility of the medium as well as its density and its rigidity. In the ether we assume that the compressibility is small compared with the rigidity, so small that the ratio of the two may be neglected, and this must still be the case, even when the ether is loaded. But when dealing with the problem of reflexion we are concerned with the refractive index of the medium for the condensational wave. This will depend on the ratio of the two effective compressibilities, as well as on that of the two effective densities, and though either of the two compressibilities may vanish when compared with the rigidities, in considering their ratio it becomes necessary to take into account any change due to the loading of the ether.

It may not be unreasonable, then, to suppose that the effective density of the ether for the condensational wave is different from the effective density for the transverse wave. This supposition would account easily for the variation from Green's formula observed when plane polarised light polarised at right angles to the plane of incidence is reflected from a transparent surface, in that it would allow us to introduce the second constant μ_0, as suggested by Haughton and Lord Rayleigh.[1]

Let us now consider Voigt's theory. With regard to the problem of reflexion his surface conditions appear to be unsound. The ether is the continuous medium, and the surface conditions must apply to it simply. The conditions of continuity demand that the actual displacements of the ether and the actual stresses over the interface, arising, of course, in part from the action of the matter, should be the same in the two media. The validity of Kirchhoff's principle has already been considered, and it has been shown that it does not lead to results in accordance with experiment, for it does not give the change of phase which in some cases accompanies reflexion.

But, while this is so, Voigt's theory shows us that the effects of the attached molecules may show themselves either in the rigidity or the density of the ether. Now, the work of Lord Rayleigh and Lorenz has proved that the effects of reflexion are due mainly, if not entirely, to differences of effective density; and so we must look to the terms in

[1] See p. 192.

Voigt's theory which affect the density as the most important. These terms are

$$-\left(r\frac{d^2}{dt^2}+n\right)(u-\text{U}).$$

The other terms,

$$\left(a\frac{d^2}{dz^2}+a'\frac{d^4}{dz^2dt^2}\right)(u-\text{U}),$$

show themselves as a variation of the effective rigidity. In order to obtain a consistent theory of reflexion we must treat these as of secondary importance compared with the first terms. Now, this is inconsistent with both theories of double refraction as advanced by Voigt, for the first condition for either is that r and n must be independent of the direction. It would seem from this that they should be the same in all media. Boussinesq adopts the opposite view. He makes his double refraction depend on the terms which correspond to r and n, and neglects the variations of the others with the direction. If we do this—and we seem to be forced into it by the further requirements of our theory—the fundamental equations in a crystal become those given by Lord Rayleigh. These, we have seen, if we assume the strict transversality of the vibrations, do not lead to Fresnel's wave surface. On the other hand, if we suppose that the vibrations in a crystal are at right angles to the ray, not to the wave normal, the result agrees with all the consequences of experiment, for we obtain Fresnel's surface as the wave surface, but we are left in a difficulty as to the normal wave.

With regard to metallic reflexion, the theory as given by Sir W. Thomson explains completely the difficulty raised by Lord Rayleigh as to a negative value for μ^2. It does not, however, enable us to decide how much of the effect is due to the fact that the highest possible free period of the ether in the metallic medium is below that of the incident light, and how much is due to opacity arising from terms such as du/dt, as supposed by Lord Rayleigh. The correct equations to which such a theory would give rise are yet unsolved, but the principles required by the solution are well known.

It seems, then, that this theory promises to afford us the solution of the difficulties which still surround theoretical optics, and to account at once for the phenomena of reflexion and refraction, dispersion and double refraction. Of course, in all cases of transparency the matter motion is infinitesimally small compared with that of the ether. The ether is to be looked upon as moving through a sort of network of fixed matter particles. Terms depending on the reaction between the ether and these fixed portions of matter will be introduced into the equations, and these terms will be expressible as functions of u, v, w and their differential coefficients. The matter particles will not move appreciably, and their movement is not necessary for the explanation of refraction and ordinary dispersion; for on Ketteler's modified theory we have, if we omit the viscous terms,

$$\mu^2=1+\frac{\beta^2}{m}+\frac{\beta^4n^2}{m\mu\,(\nu^2-n^2)},$$

and the ratio of the amplitudes is

$$-\frac{\beta^2n^2}{\mu(\nu^2-n^2)}.$$

From the value of μ^2 we see that β^2 must be comparable with m, the density of the ether, so that, except when $n^2/(\nu^2-n^2)$ is a large quantity, the ratio of the amplitudes will be inversely as the densities, for β^2/μ will be comparable with m/μ. When, however, $n^2/(\nu^2-n^2)$ is large, the matter motion becomes appreciable, and the phenomena of anomalous dispersion arise.

PART IV.

THE ELECTRO-MAGNETIC THEORY.

Chapter I.—MAXWELL'S THEORY.

§ 1. There remains now for consideration Maxwell's electro-magnetic theory. The fundamental equations of this theory are purely electrical, and are established on electrical principles. According to Maxwell, when electromotive force acts on a dielectric medium the change of condition known as electric displacement is produced. The two are connected by the equations—

$$\mathrm{P}=\frac{4\pi}{\mathrm{K}}f, \text{ etc.} \qquad (1)$$

P, Q, R being the components of the E.M.F. and f, g, h of the displacement. K is the inductive capacity. In a crystal the equation holds only for the principal axes, and along these K has three different values.

The rate of variation of the displacement given by $\dot{f}$, $\dot{g}$, $\dot{h}$ constitutes the current in the medium, and it is an essential part of the theory that—

$$\frac{d\dot{f}}{dx}+\frac{d\dot{g}}{dy}+\frac{d\dot{h}}{dz}$$

vanishes everywhere.

The current is connected with the components of the magnetic induction a, b, c by the equations—

$$\frac{dc}{dy}-\frac{db}{dz}=4\pi\dot{f} \qquad (2)$$

etc., and the magnetic force α, β, γ is given by

$$a=\mu\alpha \qquad (3)$$

etc., where μ is the coefficient of magnetic capacity.

a, b, c are also given in terms of a quantity known as the vector potential, the components of which are F, G, H, by the equations—

$$a=\frac{d\mathrm{H}}{dy}-\frac{d\mathrm{G}}{dz} \qquad (4)$$

etc., and from these it follows that

$$4\pi\mu\dot{f}=\frac{d\mathrm{J}}{dx}-\nabla^2\mathrm{F} \qquad (5)$$

etc., where

$$\mathrm{J}=\frac{d\mathrm{F}}{dx}+\frac{d\mathrm{G}}{dy}+\frac{d\mathrm{H}}{dz};$$

while the electromotive force at any point is also determined in terms of this same quantity F, G, H by the equations

$$P = -\frac{dF}{dt} - \frac{d\Psi}{dx} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

etc., Ψ being the electrostatic potential. From this it follows that

$$\mu K \frac{d}{dt}\left(\frac{dF}{dt} + \frac{d\Psi}{dx}\right) - \nabla^2 F + \frac{dJ}{dx} = 0 \quad . \quad . \quad . \quad . \quad (7)$$

etc., and the vector F travels through the medium with velocity $1/\sqrt{K\mu}$. Now, the value of this quantity can be determined by experiment, and agrees very closely indeed with the velocity of light. Thus the vector potential, and in the same way the electric displacement and the magnetic induction, travel through the medium with a velocity, as nearly as we can say, identical with that of light.

Moreover, the electric displacement corresponding to this is in the wave front, and the same is the case with the magnetic induction a, b, c. By this motion energy is conveyed through the medium, the electrostatic energy depending on the electric displacement, the electro-kinetic on the magnetic induction, and the two can be shown to be equal. Thus the theory agrees with the undulatory theory of light in assuming the existence of a medium capable of becoming a receptacle of two forms of energy. Electric displacement and magnetic induction are, then, changes of condition which can be propagated in waves of transverse disturbances through the medium with a velocity practically identical with that of light. Maxwell's theory supposes that there is an intimate connection between the vibrations which constitute light and electric displacement; according to some of his followers the two are identical, though, so far as I can judge, that is not necessary to the theory as he left it.

Now, experiment shows that the value of μ is nearly the same for all media, so that it follows that on this theory the specific inductive capacity of a medium—the ratio of its inductive capacity to that of air—should be equal to the square of the refractive index. Experiments have shown that while this law is by no means true for all substances, it is sufficiently nearly so for many to render it probable that $\sqrt{K}$ gives the most important term of the index.

In estimating the value of the comparisons we must remember that while K is determined by observations lasting over an appreciable time, the refractive index depends on vibrations of great frequency; to compare the two, then, we have to adopt some dispersion formula, and find the value of the index for waves of infinite period, and this alone is a source of error.

Again, the equations for a crystalline medium are obtained by Maxwell, and he shows that the velocity of wave propagation is given by Fresnel's construction, while the electric displacement is in the wave front, and its direction is that of the axis of the ellipse which determines the velocity. The theory is not burdened with a wave of normal vibrations, and accounts quite simply for all the phenomena of double refraction.

§ 2. The theory of reflexion and refraction of electro-magnetic waves was first given by H. A. Lorentz,[1] who follows a method of attacking the

[1] Lorentz, *Schlömilch. Zeitschrift*, t. xxii.

problem which is due to Helmholtz.[1] This we shall consider later. It was also solved by J. J. Thomson,[2] so far as the isotropic media are concerned, and by Fitzgerald.[3]

Some further developments of the theory are given in a paper by the author of this report, and read before the Cambridge Philosophical Society.[4]

In this paper the general equations for the displacement and for the magnetic induction in a crystal are given. If $\bar{a}$, $\bar{b}$, $\bar{c}$ be the principal velocities given by the equation

$$\bar{a}^2=\frac{1}{\mu K_1},$$

etc., then

$$\frac{d^2f}{dt^2}=\bar{a}^2\,\nabla^2 f-\frac{d}{dx}\left(\bar{a}^2\frac{df}{dx}+\bar{b}^2\frac{dg}{dy}+\bar{c}^2\frac{dh}{dz}\right)\quad . \quad . \quad (8)$$

etc., while

$$\frac{d^2a}{dt^2}=\bar{a}^2\frac{d^2a}{dx^2}+\bar{b}^2\frac{d^2a}{dy^2}+\bar{c}^2\frac{d^2a}{dz^2}$$

$$-\frac{d}{dx}\left(\bar{a}^2\frac{da}{dx}+\bar{b}^2\frac{db}{dy}+\bar{c}^2\frac{dc}{dz}\right)\quad . \quad . \quad . \quad (9)$$

If a wave of electric displacement S′, in a direction in which the inductive capacity is K′, be traversing the medium, the electromotive force is $4\pi S'/K'$ in the direction of displacement, and $4\pi S' \tan\chi/K'$ along the wave normal, when χ is the angle between the ray and the wave normal.

§ 3. The surface conditions implied by the theory, and used by Lorentz, J. J. Thomson, Fitzgerald, and Glazebrook, are that the electric and magnetic displacements normal to the interface are continuous, while the electric and magnetic forces in the interface are also continuous.

The formulæ obtained are identical with those given by MacCullagh and Neumann, electric displacement being substituted for the ordinary displacement of the medium.

The theory has the very great advantage over the ordinary elastic solid theory that reflexion and double refraction are both explained by variations in the same property of the medium, viz. the inductive capacity. Variations in its value from medium to medium give rise to reflexion and refraction; variations in different directions within the same medium are the cause of double refraction.

§ 4. The theory has been applied by Lord Rayleigh to account for the various phenomena [5] connected with the scattering of light by a cloud of small particles. These are deduced satisfactorily from the theory on the supposition that μ, the magnetic capacity, is a constant through the two media, and that the effects are due to variations in the inductive capacity, while, when terms of the second order in $\Delta K/K$ are included, the scattered light does not vanish—the incident light being plane polarised—in a direc-

[1] Helmholtz, *Borchardt's Journal*, Band lxxii.
[2] J. J. Thomson, *Phil. Mag.* April, 1880.
[3] Fitzgerald, *Phil. Trans.* 1881.
[4] Glazebrook, *Proc. Camb. Phil. Soc.* vol. iv. p. 155.
[5] Lord Rayleigh, 'On the Electro-magnetic Theory of Light,' *Phil. Mag.* Aug. 1881.

tion normal to the incident light, but in one inclined at an obtuse angle to that in which the light is travelling. Tyndall observed this effect when the particles scattering the light cease to be very small.

Chapter II.—Helmholtz's Theory.

§ 1. Helmholtz looks at the problem of the propagation of an electro-magnetic disturbance in a somewhat different manner, and a comparison of the two theories is given by the author of this Report.[1]

The electro-magnetic effects in the medium depend, according to Maxwell, on the values of F, G, H, the components of the vector potential, or, as Maxwell also calls it, of the electro-kinetic momentum, and if we integrate round a closed curve, the values of F, G, H satisfy the equation

$$\int \mathrm{F}dx + \mathrm{G}dy - \mathrm{H}\,dz = \iint \frac{i\cos\epsilon}{r}\, ds d\sigma \quad . \quad . \quad . \quad (10)$$

where ds is an element of the curve, i the current at any point at a distance r from ds, $d\sigma$ an element of the curve in which the current i is running, ϵ the angle between ds and $d\sigma$, and the integration on the right extends round the two curves s and σ.

From this we can show that

$$\mathrm{F} = \mu \iiint \frac{\dot{f}}{r}\, dx'dy'dz' + \frac{d\chi}{dx} \quad . \quad . \quad . \quad . \quad (11)$$

And if we put

$$\frac{df}{dx} + \frac{dg}{dy} + \frac{dh}{dz} = \frac{1}{4\pi} \nabla^2 \Phi \quad . \quad . \quad . \quad . \quad (12)$$

we find that

$$\nabla^2 \mathrm{F} - \frac{d\mathrm{J}}{dx} = -\,4\pi\mu\dot{f} + \mu\,\frac{d^2\Phi}{dxdt} \quad . \quad . \quad . \quad (13)$$

where

$$\mathrm{J} = \Phi\,\frac{d\mathrm{F}}{dx} + \frac{db}{dy} + \frac{d\mathrm{H}}{dz}.$$

Helmholtz, starting from the equation

$$\int \mathrm{F}dx + \mathrm{G}dy + \mathrm{H}dz = \iint \frac{i\cos\epsilon}{r}\, ds\, d\sigma,$$

investigates the most general form which F, G, H can have. He shows that we must write for $\frac{d\chi}{dx}$ of equation (11) the value

$$-\frac{1}{4\pi}\iiint \frac{(1-k)}{r}\,\frac{d^2\Phi}{dx'dt}\, dx'dy'dz' \quad . \quad . \quad . \quad (14)$$

where k is an unknown constant. Hence

$$\nabla^2 \mathrm{F} = -\,4\pi\mu\dot{f} + \mu\,(1-k)\frac{d^2\Phi}{dxdt} \quad . \quad . \quad . \quad (15)$$

and by comparing this with (13) we see that

$$\mathrm{J} = -\,\mu k\,\frac{d\Phi}{dt} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

[1] Glazebrook, *Proc. Camb. Phil. Soc.* vol. vi. pt. ii. See also J. J. Thomson, 'Report on Electrical Theories' p. 133 of this volume.

If it be necessary that J should vanish, then k or $\frac{d\Phi}{dt}$ must be zero. According to Helmholtz, however, J is not necessarily zero, and the equation to determine it is—

$$\mu k \mathrm{K} \frac{d^2 \mathrm{J}}{dt^2} = \Delta^2 \mathrm{J} \quad . \quad . \quad . \quad . \quad . \quad (17)$$

so that J, and therefore Φ, is propagated through the medium as a wave of normal disturbance with the velocity

$$\sqrt{\frac{1}{k\mu \mathrm{K}}}.$$

On Helmholtz's theory there may therefore be a normal wave in addition to the transverse wave. Helmholtz's theory becomes Maxwell's if we put $\Phi = 0$, and then unless the value $k = \infty$ is admissible $\mathrm{J} = 0$, and there is no normal wave. If $k = 0$ there will still be no normal wave, for its velocity will be infinite.

When we consider the problem of double refraction, we can show that all the possible directions of vibration L, M, N corresponding to a given wave normal l, m, n are given by the equation—

$$\frac{l}{\mathrm{L}} (\bar{b}^2 - \bar{c}^2) + \frac{m}{\mathrm{M}} (\bar{c}^2 - \bar{a}^2) + \frac{n}{\mathrm{N}} (\bar{a}^2 - \bar{b}^2) = 0 \quad . \quad . \quad (18)$$

There are therefore, in general, an infinite number of such directions. If, however, we are to assume that there are only two, and those the two given by Fresnel's theory, we must have $l\mathrm{L} + m\mathrm{M} + n\mathrm{N} = 0$. Thus Maxwell's solenoidal condition,

$$\frac{df}{dx} + \frac{dg}{dy} + \frac{dh}{dz} = 0 \quad . \quad . \quad . \quad . \quad . \quad (19)$$

is a necessary and sufficient condition to give Fresnel's construction.

Chapter III.—Dispersion, etc.

According to the theory as left by Maxwell, waves of all lengths travel at the same rate. Dispersion does not come into consideration. This question has been dealt with by Willard Gibbs [1] and H. A. Lorentz.[2]

§ 1. According to Gibbs's views the displacements of which we are cognisant in the phenomena of light are the average displacements taken through a space which is small in comparison with the wave length, but contains many molecules of the body. The real displacement at each point of such an elementary space probably differs considerably from the average value, and a complete theory should take into account the two. This is done in Gibbs's paper. The average displacements being ξ, η, ζ, the complete displacement is taken as $\xi + \xi'$, &c. ξ', η', ζ' are denoted as the irregular parts of the displacements. It is shown that ξ', η', ζ' are linear functions of ξ, η, ζ; they are therefore of the same period, and the phase of the irregular displacement throughout the element Dv is the

[1] J. W. Gibbs, *American Journal of Science*, vol. xxii. April, 1882.
[2] H. A. Lorentz, *Wied. Ann.* t. ix.; *Schlömilch. Zeitschrift*, t. xxiii.

same as that of the regular or average displacement, but the relations between ξ, η, ζ and ξ', η', ζ' change rapidly as we pass from point to point of the element.

The velocity of wave propagation is found by equating the maximum potential and kinetic energies of the medium. It is shown that the equations lead to Fresnel's construction in the case of a crystal if the solenoidal condition be assumed, while the relation between μ the refractive index and λ the wave length is given by

$$\frac{1}{\mu^2}=\frac{\mathrm{H}}{2\pi k^2}-\frac{2\pi_1\mathrm{H}'}{\lambda^2} \quad . \quad . \quad . \quad . \quad (20)$$

H, k, and H′ being constants. The objection which Briot made to Cauchy's theory of dispersion may be made to this. We should expect dispersion in a vacuum as well as in ordinary transparent media.

The properties of circularly polarising media are discussed in a second paper,[1] in which ξ', η', ζ' are treated as linear functions of ξ, η, ζ and their differential co-efficients; and in a third paper the fundamental equations are re-established in rather a more general form than that given by Maxwell.

The generality is gained partly by dealing with the average values of the various quantities, and partly by supposing that the relation between the E.M.F. and displacement is given by

$$[\mathrm{E}]=\phi\,[\ddot{\mathrm{U}}]+\psi\,[\mathrm{U}] \quad . \quad . \quad . \quad . \quad (21)$$

ϕ and ψ being two arbitrary functions, and [ ] indicating that the average value is taken. In the simple theory ϕ is a constant, and equal to $4\pi/\mathrm{K}$, and ψ zero, and this will not give dispersion.

There seems, however, to be no reason—as has been pointed out by Professor Fitzgerald—against applying to the oscillations of the electro-magnetic field the methods and reasoning developed in the third part of this report. Almost the whole of the work can be translated into the language of the electro-magnetic theory at once. Periodic electric displacement in the ether will produce periodic electric displacement in the matter, and the relations between the two will depend on the ratio of the period of the ether vibrations to the possible free periods of the electric oscillations in the matter molecules; and it is not difficult to see how the action between the two might depend on the relative electrical displacements and their differential coefficients.

§ 2. Maxwell[2] has given a theory of the magnetic rotation of the plane of polarisation on this theory. He assumes (1) that the effect of magnetic force is to set up molecular vortices in the medium; (2) that the components of the magnetic force obey the same law as the components of the strength of a vortex in hydrodynamics; and (3) that there arises in the value for the kinetic energy of the medium a term of the form $2\mathrm{C}(\alpha\omega_1+\beta\omega_2+\gamma\omega_3)$, ω_1, ω_2, ω_3 being the components of the angular velocity, and α, β, γ of the magnetic force.

For the case of waves travelling parallel to z the kinetic energy is shown to be

$$\mathrm{T}=\tfrac{1}{2}\rho\,(\dot\xi^2+\dot\eta^2+\dot\zeta^2)+c\gamma\left(\dot\eta\,\frac{d^2\dot\xi}{dz^2}-\dot\xi\frac{d^2\dot\eta}{dz^2}\right) \quad . \quad . \quad (22)$$

[1] J. W. Gibbs, *American Journal of Science*, vol. xxiii. June, 1882.
[2] Maxwell, *Electricity and Magnetism*, vol. ii. p. 40.

and the equations of motion,

$$\rho \frac{d^2\xi}{dt^2} + c\gamma \frac{d^3\eta}{dz^2 dt} = A_0 \frac{d^2\xi}{dz^2} + A_1 \frac{d^4\xi}{dz^4} +, \text{ etc.} \quad . \quad . \quad (23)$$

From this it follows that the rotation per unit length is

$$\theta = mc\gamma \frac{i^2}{\lambda^2}\left(i - \lambda \frac{di}{d\lambda}\right) \quad . \quad . \quad . \quad . \quad (24)$$

where i is the index of refraction, and this formula agrees well with experiment.

It should be noticed that in obtaining this formula Maxwell deals with the displacements of an ordinary medium; the forces assumed are those arising from the elastic reactions of this medium, the vortex motion in which is connected with the magnetic force. The displacements are not treated as identical with the electric displacements, nor is any indication given of the connection between the two.

§ 3. Fitzgerald, in the paper already mentioned, applies the theory to the case of reflexion from a magnetic medium. He finds that when plane polarised light is reflected directly from such a medium, the reflected light is slightly elliptically polarised. This is not in accordance with Kerr's experimental result, but Fitzgerald treats the iron as a transparent, or nearly transparent, substance with a real refractive index.

§ 4. It was shown by E. H. Hall that when a current passes across a conductor in a magnetic field an electromotive force is produced whose strength is proportional to the product of the current and the strength of the field, and whose direction is at right angles to the plane containing the current and the field.

By introducing into the equations for the electromotive force terms expressing this, so that they become

$$P = -\frac{dF}{dt} - \frac{8\pi\mu\bar{C}}{\rho}(\gamma\dot{g} - \beta\dot{h}) \quad . \quad . \quad . \quad . \quad (25)$$

etc., Prof. Rowland [1] has calculated the magnetic rotation of the vectors F, G, H, and, on the assumption that a similar effect will be produced in a dielectric, arrives at the same formula as that given by Maxwell.

§ 5. The main difficulty of the theory, and the one which stands most in the way of its general acceptance, is the difficulty of forming a clear physical idea of what electric displacement is, and various analogies have been suggested with a view to rendering the difficulty less serious. One of these, due to Helmholtz,[2] is developed in a paper on the molecular vortex theory of electro-magnetic action.[3] It is shown there that, if the components of the magnetic force be identified with the molecular rotations in a continuous medium in which the displacements are ξ, η, ζ, then the components of the electro-kinetic momentum are equal to $\frac{1}{2}\mu\dot{\xi}$, etc.; and the equations of the electrical field in a conductor would imply that the medium in the conductor has the properties of a viscous fluid, while in a dielectric, so far as the motion to which the undulatory effects are due is

[1] Rowland, *Phil. Mag.* April, 1881.
[2] Helmholtz, *Crelle Journal*, t. lxxii.
[3] Glazebrook, *Phil. Mag.* June, 1881.

concerned, its properties are those of an elastic solid in which the electrical displacement f is given by

$$8\pi f = -\nabla^2\xi + \frac{d}{dx}\left(\frac{d\xi}{dx}+\frac{d\eta}{dy}+\frac{d\zeta}{dz}\right) \quad . \quad . \quad . \quad (26)$$

The objection that it is impossible to maintain a continuous molecular rotation in an elastic solid may be made to this analogy. It seems, however, possible that, as suggested by Professor Stokes when considering the problem of aberration, the ether may behave as a perfect fluid for all motions involving more than a very small relative displacement of its parts, while for such small displacements as are contemplated in the theory of light it has, in a dielectric, an appreciable rigidity. In a conductor the effects of this rigidity, if it exist, are masked by the more powerful effects of the viscosity. The fluid is no longer perfect.

Chapter IV.—Rowland's Theory of the Propagation of Plane Waves.

§ 1. The propagation of waves of electro-magnetic disturbance from a given source has been recently very fully considered by Professor Rowland,[1] and we proceed to give some account of his paper.

Rowland considers very generally the solution of the equations—

$$\frac{d^2F}{dt^2} = V^2\nabla^2F, . \quad . \quad . \quad . \quad . \quad (27)$$

etc., and allied equations given by the system

$$F_{m+1} = \frac{dH_m}{dy} - \frac{dG_m}{dz} \quad . \quad . \quad . \quad . \quad (28)$$

so that F, G, H satisfy the solenoidal condition. He puts

$$F_0 = C_n\rho^n\Phi_{-(n+1)}\, e^{(a-ib)(\rho-Vt)},$$

$\Phi_{-(m+1)}$ being a spherical harmonic, and C_n a function of ρ.

He finds

$$\frac{d^2C_n}{d\rho^2} + 2\,(a-ib)\frac{dC_n}{d\rho} - \frac{n(n+1)}{\rho^2}C_n = 0 \quad . \quad . \quad (29)$$

whence

$$C_n = C_0\left\{1 - \frac{n}{2}\frac{n+1}{c\rho} + \frac{n\,(n^2-1^2)}{2.4}\frac{(n+2)}{c^2\rho^2} + . \quad . \quad . \quad .\right\} \quad (30)$$

where $c = a - ib$.

He then takes, as a special solution,

$$F_0 = C_n\rho^n\frac{d\Phi_{-n}}{dx}e^{c(\rho-Vt)} \quad . \quad . \quad . \quad . \quad (31)$$

and

$$F_1 = cC_{-1}\rho^{n-1}\left\{y\frac{d\Phi_{-n}}{dz} - z\frac{d\Phi_{-n}}{dy}\right\}e^{c(\rho-Vt)} \quad . \quad . \quad (32)$$

etc., and treats the case of symmetry round the axis of x, for which

$$\Phi_{-n} = \frac{(-1)^nQ_{n-1}}{\rho^n n!},$$

Q_{n-1} being a zonal harmonic with the axis of x for axis.

[1] Rowland, *American Journal of Mathematics*; *Phil. Mag.* June, 1884.

Let θ be the angle between this direction and that to the point at which the disturbance is required, ρ the distance to the point, and α the angle between the plane $xO\rho$ and some fixed plane.

Let Θ', Θ'' denote disturbances perpendicular to the radius vector in the plane $xO\rho$,

P′ P″ along the radius vector, and

N′ N″ normal to the wave plane $xO\rho$.

Then it follows that if we have small electric displacements $X'e^{-ib(R-Vt)}$ parallel to x throughout the small sphere ($\frac{4}{3}\pi R^3 = dv$), that

$$\left.\begin{aligned} \Theta' &= -\frac{2C_0+C_2}{C_0}\frac{b^2X'}{8\pi\rho}\sin\theta e^{-ib(\rho-Vt)}dv \\ P' &= \frac{C_1}{C_0}\frac{3ibX'}{4\pi\rho^2}\cos\theta e^{-ib(\rho-Vt)}dv \end{aligned}\right\} \quad . \quad . \quad (33)$$

$$N' = \Theta'' = P'' = 0$$

$$\left.N'' = \frac{3b^2X'\sin\theta}{2\pi\rho}\frac{C_1}{C_0}e^{-ib(\rho-Vt)}dv\right\} \quad . \quad . \quad . \quad . \quad (34)$$

where

$$\left.\begin{aligned} C_1 &= C_0\left(1-\frac{i}{b\rho}\right) \\ C_2 &= C_0\left(1-\frac{3i}{b\rho}-\frac{3}{b^2\rho^2}\right) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (35)$$

This agrees with the results given by Stokes and Lord Rayleigh, already quoted,[1] N″ being proportional to the rotation. The effect of a general arbitrary electric and magnetic displacement is then found.

In considering the optical problem it is pointed out that electric displacement is always accompanied by magnetic, and that the effects of the two must be considered, and according to the views of Professor Rowland the two must be considered independently. From the relation between the electrostatic and electromagnetic energy, it follows that if there be an electric displacement $X'e^{ibVt}$ there will be a magnetic $Y''e^{ibVt}$ where

$$Y'' = \frac{4\pi}{V\kappa}X'.$$

The electric displacement at any other point of space is found and expressed as below. Let the origin be the point at which X′, Y″ act; the axis of z the normal to the plane of $X'aY''$; ρ the direction in which the effect—at a point A—is required; the angle $zOA = \theta$, and the angle between zOA and $zOx = \phi$; and let P′, Θ′, Φ′ be the displacements along OA, and normal to θ and ϕ.

Then

$$\left.\begin{aligned} \Theta' &= \frac{3b^2X'V}{8\pi\rho}\cos\phi\left[(1+\cos\theta)\left(1-\frac{i}{b\rho}\right)-\frac{\cos\theta}{b^2\rho^2}\right]e^{-ib(\rho-Vt)} \\ \Phi' &= -\frac{3b^2X'V}{8\pi\rho}\sin\phi\left[(1+\cos\theta)\left(1-\frac{i}{b\rho}\right)-\frac{1}{b^2\rho^2}\right]e^{-ib(\rho-Vt)} \\ P' &= \frac{3ibX'V}{4\pi\rho^2}\sin\theta\cos\varphi\left[1-\frac{i}{b\rho}\right]e^{-ib(\rho-Vt)} \end{aligned}\right\} (36)$$

[1] See p. 201.

And we can show that in the value of Θ' it is the 1 in $(1 + \cos\theta)$ which comes from the assumed magnetic disturbance, while in Φ' it is the $\cos\theta$ in the same term.

The magnetic disturbance produces no effect in the value of P′. Neglecting the magnetic disturbance we arrive at Stokes's result for the effect of a disturbance $X'e^{ibVt}$ on the medium, which is used by Rayleigh in the paper on the blue of the sky.

Now we may note that the result of the experiments on scattered light seems to disprove this hypothesis of Rowland's as to the necessity of considering the two disturbances, for according to him the intensity is the same at all points in the plane xy at the same distance from O. This is not true; the intensity varies as $\sin^2\alpha$ if α is the angular distance of the point from the axis of x. Again, it is true, of course, that the magnetic disturbance accompanies the electric, but it accompanies it as a consequence. If we produce, by some impressed force, a variable electric displacement at a point in the medium, and calculate the effect due to this, we have done all that is necessary. There will, it is true, be magnetic displacement, but it can be calculated from the electric.

Rowland's results do not apply to the case of a wave being propagated through an aperture, for in this case we have no right to assume that the disturbance produced by an element is symmetrical round the direction of vibration. We have not a single particle or an indefinitely small sphere vibrating and sending out its effects in spherical waves; we have a state of motion coming in from behind the aperture, and being continually propagated across it at a given point P and at time t_0, we must consider the circumstances at any point O of the aperture at a time t_0 such that $OP = b(t - t_0)$. For these will be the initial circumstances so far as we are concerned; and at this time t_0, O has an initial velocity and an initial displacement. Both these require to be considered in dealing with the question, and we have to adopt Stokes's[1] method of solution, and we again arrive at his theorems with regard to the relation between the direction of vibration and the direction of diffraction.

§ 2. The electro-magnetic theory, if we accept its fundamental hypotheses, is thus seen to be capable of explaining in a fairly satisfactory manner most of the known phenomena of optics. The great difficulty is, as we have said, to account for the properties which the medium must have in order to sustain electrical stresses. These consist in an electrostatic field of a hydrostatic pressure $KR^2/8\pi$, combined with a tension $KR^2/4\pi$ along the lines of force; R being the resultant electrical force, and K the inductive capacity. There will therefore be a difference of pressure in different directions in the ether.

Combined with this difficulty there is another of a similar kind, that of realising mechanically what electric displacement is, of forming for oneself a physical idea of a change of structure in some medium of unknown properties which shall obey the laws implied by the various equations satisfied by the components of electrical displacement.

Optical effects are certainly due to changes, periodic in space and time, of some properties of a medium which we call the ether. Electromagnetic effects are also due to variations in properties—it may be the same as those which give rise to light—of the same ether. When the

[1] On this point reference has already been made, see p. 206.

electro-magnetic effects become rapidly periodic they travel with the velocity of light, and the direction to which the change of property is related is in the wave front, at least for isotropic media.

The rigidity or quasi-rigidity through which the medium has the power of propagating these transverse waves of small displacement may be given to it through other motions which are going on independently of the light. The free passage of the planets through space proves that it can have little if any viscosity or rigidity, though, according to the views of Professor Stokes, while behaving as a perfect fluid for all appreciable motions, it might conceivably be rigid for the very small displacements in a light-wave. Taking Sir W. Thomson's estimate of the density of the ether as about 10^{-22} grammes per cubic centimetre, the rigidity required for the propagation of light would be about 10^{-1}. The rigidity of glass is about $2{\cdot}5 \times 10^{11}$. While it might, then, be conceivable that the ether should have this very small rigidity and yet offer no appreciable resistance to the earth's motion, it is difficult to reconcile this with its power of standing electric stress, and we are forced to conclude that the change implied in electric displacement is much more than a mechanical displacement of the molecules of a perfect fluid. A quasi-rigidity might be conferred on the fluid by filling it with vortices, and it might thus become capable of conveying transverse waves and of standing electric stress. Electric and magnetic polarisation would then consist in definite arrangements of the vortex rings or filaments. Changes in these arrangements, or in some of the properties connected with them, would constitute electric and magnetic displacements, and possibly also light.

We should then have a complete electro-magnetic theory of optics, or rather a complete theory of the ether embracing electro-magnetism and optics, but towards this theory our present knowledge has made only a small advance.

Report of the Committee, consisting of Professors RAMSAY, TILDEN, MARSHALL, *and* W. L. GOODWIN (*Secretary*), *appointed for the purpose of investigating certain Physical Constants of Solution, especially the Expansion of Saline Solutions.*

YOUR Committee have to report as follows:

They have obtained apparatus for determining the rates of expansion of saline solutions from $-20°$ C. to $+60°$ C.

They have devised experiments for determining the distribution of a weighed quantity of water between molecular weights of two salts, the three substances being placed in separate vessels in the same enclosed space kept at a constant temperature.

But further progress in either of these directions was interrupted by the continued illness of one of the Committee.

Your Committee respectfully ask for reappointment.

Third Report of the Committee, consisting of Professors WILLIAMSON, DEWAR, FRANKLAND, CRUM BROWN, ODLING, *and* ARMSTRONG, Drs. HUGO MÜLLER, F. R. JAPP, *and* H. FORSTER MORLEY, *and* Messrs. A. G. VERNON HARCOURT, C. E. GROVES, J. MILLAR THOMSON, H. B. DIXON (*Secretary*), *and* V. H. VELEY, *reappointed for the purpose of drawing up a statement of the varieties of Chemical Names which have come into use, for indicating the causes which have led to their adoption, and for considering what can be done to bring about some convergence of the views on Chemical Nomenclature obtaining among English and foreign chemists.*

AN account of the authorship of some of the various systems of nomenclature which have been devised for the purpose of distinguishing between compounds formed by the union of the same elements in different proportions, has been given in the 'Historical Notes' prefixed to the Second Report of this Committee. Among these systems the use of the terminations *ous* and *ic*, to denote respectively lower or higher degrees of saturation of one element or group with another element or group, is perhaps that which has met with the widest acceptance. This system further directs that when electro-negative groups, the names of which end in *ous* and *ic*, unite with electro-positive groups to form salts, these terminations are to be changed into *ite* and *ate* respectively.

Before proceeding to discuss the practical application of this system, it may be well to point out, as a minor etymological detail, that the literal meaning of the terminations *ous* and *ic* has altered since they were first employed. Thus *ous* (Latin *osus*) ought to denote, on the part of the compound, *richness in* that element to the name of which the termination is attached. For example, *cuprous* (*cuprosus*) means 'rich in copper': *cuprous* oxide is primarily an oxide which is *richer in copper* than *cupric* oxide, and only by implication an oxide which is *poorer in oxygen.* This implied signification is, however, that in which the name *cuprous oxide* is nowadays employed. A curious result of this change of literal meaning is to be found in the use of the prefix *hypo* to denote a still lower degree of saturation than that expressed by *ous.* Thus the name *hyponitrous acid* is taken to denote an acid containing still less oxygen than nitrous acid; whereas *hyponitrous* really means 'less rich in nitrogen,' which is the very opposite. Had the etymology been logically carried out, the prefix ought to have been *hyper.* A similar confusion of ideas is displayed in the use of the prefixes *hyper* and *per* at the other end of the scale; in place of these, *hypo* ought to have been employed. *Perchromic acid* does not, as its name literally taken signifies, contain more chromium than *chromic acid*: it contains less, and ought consequently to have been termed *hypo*-chromic acid.

It need hardly be said that it would be ill-advised to attempt to change a system so firmly established as that involved in the present use of these prefixes *hypo* and *hyper*; and in the above remarks on the etymology of the subject, nothing of the kind is intended. No ambiguity can arise from the use of terms about the meaning of which everyone is agreed, and their mere etymological accuracy is, in view of this all-important consideration, of secondary importance.

The following list will show the application of the *ic* and *ous* nomenclature to salts and salifiable oxides:—

I. *List of Salts where Two or more Series of Compounds are formed.*[1]

Name denoting metallic radical of salt	Formula of corresponding oxide	Name denoting metallic radical of salt	Formula of corresponding oxide
Cuprous	Cu_2O	Chromous	CrO
Cupric	CuO	Chromic	Cr_2O_3
Mercurous	Hg_2O	Uranous	UO_2
Mercuric	HgO	Uranic (Uranylic)	UO_3
Aurous	Au_2O	Manganous	MnO
Auric	Au_2O_3	Manganic	Mn_2O_3
Thallous	Tl_2O	Ferrous	FeO
Thallic	Tl_2O_3	Ferric	Fe_2O_3
Stannous	SnO	Cobaltous	CoO
Stannic	SnO_2	Cobaltic	Co_2O_3
Cerous	Ce_2O_3	Platinous	PtO
Ceric	CeO_2	Platinic	PtO_2

Names corresponding with *platinous* and *platinic* would be applied to the corresponding oxides and salts of the other metals of the platinum group—distinguishing, however, the other oxides and salts of this group by numeral or other designations.

The designations given in this Table to the various higher and lower series of salts and salifiable oxides have been employed with almost complete uniformity by all chemists who have adopted this system of nomenclature.

As a metal rarely—if ever—forms more than two salifiable oxides, the *ous* and *ic* terminations generally suffice for purposes of distinction so far as the salts of metals are concerned.

The practice of further employing these terminations in the case of acid-forming oxides does not lead to confusion, since these oxides are distinguished by the name *anhydride* (or *acid*). Thus we have

CrO	Cr_2O_3	CrO_3
Chromous oxide.	Chromic oxide.	Chromic anhydride (Chromic acid.)

Indifferent oxides have frequently been classified and named by regarding them as compounds of salifiable, with acid-forming oxides, Cr_2O_4 being termed *chromic chromate.* For stages lower than *ous*, the prefixes *hypo* and *sub* are employed. Custom appears to have restricted *hypo* chiefly to acids and to acid-forming oxides, *sub* to salifiable and to indifferent oxides.

With regard to the termination *ous*, the minor question arises, how far this termination ought to be written in the forms *ious* and *eous.* The answer is: as seldom as possible. 'Cupreous' has generally given way to 'cuprous'; no one writes 'chrom*i*ous' (although the name of the metal is 'chrom*i*um'); and there is no reason why such names as 'ruthenious' and 'iridious' should not equally be shorn of their superfluous penultimate syllable.

A further question, concerning which considerable difference of opinion has prevailed, is whether any *ous* or *ic* terminations ought to be employed in the names of salts of which only one class is known—thus *magnesic sulphate* instead of *magnesium sulphate.* There is something to

[1] In this list the term 'salt' is taken to include 'haloïd salts,' but to exclude the halogen compounds of those elements whose oxides do not yield oxy-salts with acids.

be said here for both systems; and, as the diversity of practice does not lead to confusion, and consequently does but little harm (beyond in each case offending the ears of those accustomed to the opposite system), the question need not be regarded as a vital one. Objections which have been urged against the use of any termination in such cases are that chemists have not always been able to agree as to which termination is to be used in a given case, and that, apart from this, the practice causes beginners erroneously to surmise the existence of a second series of salts. The objection on the other side is that the omission of the terminal 'ic' breaks the uniformity of the system and leads beginners to suppose that barium sulphate, for instance, has a different constitution from cupric sulphate. In the case of carbon compounds, on the other hand, there is a distinct advantage in affixing *ic* to the names of the positive radicals in ethereal salts. A neglect of this precaution leads to ambiguity—at all events in the *spoken* name. Thus, though there is no ambiguity in the name *ethyl phenylacetate* when written, yet the ear cannot distinguish between it and *ethylphenyl acetate.* This ambiguity is obviated by the use of the termination *ic*: thus, *ethylic phenylacetate* and *ethylphenylic acetate.*

In the use of the terminations *ous* and *ic* to distinguish different series of *acids and acid-forming oxides*, the practice of chemists has also been very uniform. Indeed, with the exception of one or two isolated cases almost perfect unanimity has prevailed.

To sum up, the *ous* and *ic* terminations when employed for purposes of distinction in cases where two series of oxides, acids, salts, &c., are known, have been almost free from ambiguity, and for this reason deserve to be retained. On the other hand, in cases where only one series is known, those chemists who have employed one or other of these terminations have occasionally differed as to which ought to be used: the difficulty may be solved, as it has been done by some chemists, by avoiding the use of any termination in such cases.

In complex cases where the above modes of naming prove inadequate, recourse may be had to numeral designations. These appear especially admissible in cases where an oxide occurs which is intermediate between the *ous* and *ic* stage, and at the same time cannot be classed as a compound of oxides already classified and named.

In applying numeral designations, it is most important to select only such as are free from hypothesis and which afford correct information. In this respect, chemists appear of late years not to have been sufficiently careful. As an example, *arsenious oxide* may be quoted; this compound is frequently termed 'arsenic trioxide,' the formula being written As_2O_3, and it is tacitly assumed that the molecule contains three oxygen atoms. There are three objections to this name:—(1) That, assuming the formula on which it is based to be correct, it affords no information as to the number of *arsenic* atoms associated with the *three* oxygen atoms; (2) that it involves the assumption that arsenious oxide does not vary in molecular weight, whatever its physical state; and (3) that the formula of *gaseous* arsenious oxide is As_4O_6.

In employing numeral designations to indicate molecular composition in cases where this is established, it is therefore important to express the number of atoms of each constituent element, as *dicarbon hexachloride*, $C_2 Cl_6$. But in the case of solid and liquid bodies of which the molecular weight is either unknown or may vary with temperature, the name should indicate merely the relative proportions in which the constituents are associated; or, more explicitly, the name should indicate the propor-

tion of the radical associated with what may be termed the characteristic element of the compound. No difficulty occurs in the case of the chlorides, or analogous compounds with the monad elements generally, these being termed mono-, di-, tri-, tetra-, penta-, or hexa-chloride, &c., according as combination is in the proportion of 1, 2, 3, 4, 5, or 6 atoms of chlorine to 1 atom of the characteristic element. The application of this system would involve the use of the names tin dichloride and iron trichloride (not sesqui-chloride) for stannous and ferric chlorides respectively, names which accurately express the relative proportions of chlorine to metal in these compounds without any hypothesis as to their molecular composition —a composition, which in the case of the former compound, at all events, certainly depends on temperature. It will, however, involve a slight departure from the existing practice when applied to oxides, sulphides, and other compounds of polyad elements; thus oxides of the type $(R_2)''O$ would be termed *hemi*-oxides, since they consist of the characteristic element and oxygen in the proportion of *one* atom of the former to *half* an atom of the latter. Oxides of the type $(R_2)^{vi}O_3$ would be termed *sesqui*-oxides, since the characteristic element and oxygen are present in the proportion of *one* of the former to *one and a half* of the latter. Oxides of the type $R_2\,O_5$ would be termed *sesterti*-oxides, as they contain oxygen and the characteristic element in the proportion of *two and a half* atoms of the former to *one* of the latter. Oxides of the types RO, RO_2, RO_3, and RO_4, would be termed respectively *mono-*, *di-*, *tri-*, and *tetr*-oxides.

Acid Salts.

There are two distinct classes of salts to which this name has been given:—

1. Salts with two or more metals, one of the metals being hydrogen.
2. Salts formed from these by the removal of water.

Until comparatively lately, no attempt was made to give distinctive names to these two classes, except that sometimes the words hydratic and anhydrous were used to distinguish them. The distinctive names—pyrophosphate, metaphosphate—which Graham gave to the two sets of anhydrous acid phosphates were founded on the supposition that the phosphoric acid (PO_5) existed in them in two modifications, different from the acid of the ordinary phosphates.

The nomenclature used by nearly all chemists from the beginning of this century until about 1860 is illustrated on tables 3–6. Acid salts in which for the same quantity of base there is 2, 3, . . . &c. times as much acid as there is in the normal salt are called bi——ate, ter——ate, &c. (in German, doppelt (or zweifach)——saures Salz, dreifach——saures Salz, &c.) In English and French the Latin adverbial numerals *bis* or *bi*, *ter*, &c. seem always to have been used until about twenty years ago, when Greek adverbial numerals were introduced for the anhydrous acid salts. Watts's Dictionary and Naquet are the first English and French authorities in which we have observed this change.

Basic Salts.

There are two distinct classes of salts to which this name has been given:—

1. Salts with two or more salt radicals, one of the salt radicals being hydroxyl.
2. Salts formed from these by the removal of water.

These were not distinguished by name until quite recently, and are still very often confused.

The nomenclature in general use is illustrated on tables 8–12.

Basic salts of oxygen acids in which for the same quantity of base there is $\frac{1}{2}$, $\frac{1}{3}$, &c. as much acid as there is in the normal salt are called di——ate, tri (or tris)——ate, &c. (in German, halb——saures Salz, drittel——saures Salz, &c.)

Basic salts of oxygen acid were also named by the proportion of base to acid, the proportion in the normal salt being taken as unity—bibasic, terbasic, &c. salts (in German, zweifach, dreifach, etc. basische Salze). Thus *tris*nitrate (drittel saures salpetersaures Salz) is the same as *ter*basic nitrate (dreifach basisches salpetersaures Salz), Latin adverbial numerals being used for multiples, and Greek adverbial numerals for submultiples.

The compounds of basic oxides with haloïd salts (corresponding to the basic salts of the oxygen acids) are variously named; thus, oxychloride, bisoxychloride, basic chloride, bibasic chloride. The numerals here refer not to the number of atoms of oxygen and halogen, but to the proportion of metal combined with oxygen and halogen respectively (or perhaps more correctly to the proportion of *equivalents* of oxygen and halogen); thus $2PbO.PbCl_2$ is bisoxychloride, or bibasic chloride. It is to be noted that corresponding basic haloïd and oxygen salts have not the same numeral; as—

$PbO.PbCl_2$ is basic chloride (einfach basisches Chlorid).

$PbO.Pb(NO_3)_2$ is bibasic nitrate (zweifach basisches Salz), because it is $2PbO.N_2O_5$.

$2PbO.PbCl_2$ is bibasic chloride (zweifach basisches Chlorid).

$2PbO.Pb(NO_3)_2$ is terbasic nitrate (dreifach basisches Salz), because it is $3PbO.N_2O_5$.

Sulphur Salts.—Table 14.

These have sometimes, especially in German, been named as double sulphides, but usually, in Latin, English, French, and recently also in German, follow the names of the corresponding oxygen salts.

Sulphur Basic Salts.—Table 13.

Compounds of normal salts with sulphides of the metal. These were discovered by H. Rose, and called by Berzelius sulphur basic (schwefel basisch), as corresponding to the compounds of normal salts with the basic oxide. This nomenclature has not been generally adopted, and, as will be seen from the table, there is little uniformity in naming these substances.

Double Salts.

With very few exceptions, these may be classified in two sets. 1. With a common salt radical. 2. With a common metal. 1. With a common salt radical. Here again there are two kinds. (*a*) Salts of polybasic acids. (*b*) Compounds of two haloïd salts, or of a haloïd salt, with a compound of a halogen and a non-metallic element.

(*a*) These are named consistently with the names of the simple salts; as phosphate of magnesia and ammonia, phosphorsaure ammoniak-magnesia, magnesium ammonium orthophosphate, ammonic magnesic phosphate, or, with what may perhaps be called an adverbial modification of the first adjective, ammonio-magnesic phosphate.

(*b*) Of these we may take as examples $2KF, SiF_4$; $2KCl, PtCl_4$; $2KCN, Pt(CN)_2$; KF, BF_3; $KCl, AuCl_3$; $4KCN, Fe(CN)_2$; $3(KCN), Fe(CN)_3$. See Tables 15, 16, 17.

These have been named on three different principles :—

(α) As double fluorides, chlorides, etc.; for instance, fluoride of silicon and potassium, fluorkieselkalium.

(β) As compounds of the positive metal with a compound salt radical; for instance, ferrocyanide of potassium, silicofluoride of potassium, kieselfluorkalium.

(γ) As analogues of oxygen salts; for instance, fluosilicate of potassium, potassium fluosilicate, potassium chlorplatinate, chloraurate, cyanaurate.

The third system seems only to be used when there is really a corresponding oxygen compound.

2. With a common metal. As a well-known substance mentioned by most systematic writers, emerald green has been selected—table 18. It will be seen that where a name is given, it is either acetate and arsenite, or a combined name, acetoarsenite, or arsenigessigsaures Salz.

List of Authorities referred to by their numbers in the following tables.

No.	Author	Edition	Date	No.	Author	Edition	Date
1	Thomson	II.	1804	20	Miller	I.	1856
2	Thomson	IV.	1810	21	Regnault	V.	1859
3	Thomson	V.	1817	22	Rose (French) . .	—	1862
4	Brande	I.	1819	23	Watts's Dictionary and Supplements	—	1863–81
5	Thomson	VII.	1831				
6	Brande	IV.	1837	24	Naquet	II.	1867
7	Öngren (Table to Berzelius)	IV.	1838	25	Rose (Finkener) .	VI.	1867–71
				26	Fownes	X.	1868
8	Brande	V.	1841	27	Williamson . . .	II.	1868
9	Graham	I.	1842	28	Wurtz's Dictionary .	—	1869–76
10	Gmelin	IV.	1843–4	29	Bloxam	II.	1872
11	Liebig (Geiger) . .	V.	1843	30	Regnault Strecker-Wislicenus	IX.	1877
12	Mitscherlich . . .	IV.	1844				
13	Handwörterbuch .	I. & II.	1848–64	31	Kolbe, Kurzes Lehrbuch	—	1877–8
14	Kopp's Geschichte (vol. iv.)	—	1847				
				32	Fownes	XII.	1877
15	Kane	II.	1849	33	Miller	VI.	1878
16	Graham	II.	1850 & 1858	34	Roscoe and Schorlemmer	—	1878–81
17	Regnault	III.	1851	35	Frankland and Japp	—	1884
18	Fownes	V.	1854	36	Kolbe (Humpidge).	—	1884
19	Otto	III.	1855–60				

I.

1. Muriat of lime.
2. Muriate of lime.
3. Chloride of calcium (also muriate of lime).
4. Chloride of calcium.
5. Chloride of calcium.
6. Chloride of calcium (cal + C).
7. Chloretum calcicum (CaCl).
8. Chloride of calcium or muriate of lime (Cal + C).
9. Chloride of calcium (CaCl).
10. Chlorcalcium (CaCl).
11. Chlorcalcium (calcium chloratum) ($CaCl_2$).
12. Chlorcalcium (CaCl).
13. Calciumchlorid, chlorcalcium (Salzsaurer Kalk) (Ca$\not{C}l$), 1859.
14. Chlorcalcium.
15. Chloride of calcium (CaCl + 6Aq).
16. Chloride of calcium (CaCl).
17. Chlorure de calcium (CaCl).
18. Chloride of calcium (CaCl).
19. Chlorcalcium (CaCl).
20. Chloride of calcium.
21. Chlorure de calcium (CaCl).
22. —
23. Chloride of calcium ($CaCl_2$). 2nd Supp. Calcium chloride.
24. Chlorure de calcium.
25. Chlorcalcium.

26. Calcium chloride ($CaCl_2$).
27. Calcic chloride (Cl_2Ca).
28. Chlorure de calcium.
29. Chloride of calcium ($CaCl_2$).
30. Chlorcalcium ($CaCl_2$).
31. Chlorcalcium ($Ca''Cl_2$).
32. Calcium chloride ($CaCl_2$).
33. Calcic chloride (or chloride of calcium) ($CaCl_2$).
34. Calcium chloride (chloride of calcium) ($CaCl_2$).
35. Calcic chloride ($CaCl_2$).
36. Calcium chloride ($CaCl_2$).

II.

1. Sulphat of soda.
2. Sulphate of soda.
3. Sulphate of soda.
4. Sulphate of soda.
5. Sulphate of soda.
6. Sulphate of soda ($S + s'$).
7. Sulphas natricus ($\dot{Na}\dddot{S}$)
8. —
9. Sulphate of soda ($NaO,SO_3 + 10HO$).
10. Einfach schwefelsaures Natron.
11. Schwefelsaures Natron (natrum sulphuricum) ($NaO,SO_3,10Aq$).
12. Schwefelsaures Natron ($\dot{Na}\dddot{S} + 10Aq$).
13. Schwefelsaures Natron, neutrales, 1859.
14. Schwefelsaures Natron.
15. Sulphate of soda ($NaO.SO_3 + 10Aq$).
16. Sulphate of soda (NaO,SO_3).
17. Sulfate de soude (NaO,SO_3).
18. Sulphate of soda (NaO,SO_3).
19. Schwefelsaures Natron (NaO,SO_3).
20. Sulphate of soda (NaO,SO_3).
21. Sulfate de soude ($NaO.SO_3$).
22. —
23. Normal or neutral sulphate of sodium. 2nd Supp. sodium sulphate (Na_2SO_4).
24. Sulfate neutre de soude.
25. Schwefelsaures Natron.
26. Sodium sulphate (SO_4Na_2)
27. Sodic sulphate (Na_2SO_4).
28. Sulfate neutre de sodium.
29. Sulphate of soda (Na_2O,SO_3).
30. Neutrales schwefelsaures Natrium, oder Dinatriumsulfat (Na_2SO_4, $10H_2O$).
31. Schwefelsaures Natron, neutrales ($SO_2{}^{ONa}_{ONa} + 10H_2O$).
32. Sodium sulphate.
33. Sodic sulphate, or sulphate of sodium (Na_2SO_4).
34. Normal sodium sulphate (also sulphate of soda).
35. Sodic sulphate (SO_2Nao_2).
36. Sodium sulphate.

III.

1. —
2. Supersulphate of soda.
3. Bisulphate of soda.
4. Bisulphate of soda.
5. Bisulphate of soda.
6. Bisulphate of soda.
7. —
8. Bisulphate of soda.
9. Bisulphate of soda ($HO,SO_3 + NaO,SO_3$).
10. —
11. Saures (od. doppelt) schwefelsaures Natron ($NaO,2SO_3 + Aq$).
12. Schwefelsaures Natron und schwefelsaures Wasser, zweifach schwefelsaures Natron ($\dot{Na}\dddot{S}^2 + 3\dot{\bar{H}} = \dot{Na}\dddot{S} + \dot{\bar{H}}\dddot{S} + 2\dot{\bar{H}}$).
13. Schwefelsaures Natron, zweifach saures, wasserhaltendes Salz ($NaO,SO_3 + \bar{H}O,SO_3$).
14. Saures schwefelsaures Natron.
15. Bisulphate of soda ($NaO,SO_3 + HO,SO_3$).
16. Bisulphate of soda ($HO,SO_3 + NaO,SO_3$).
17. Bisulfate de soude ($NaO.SO^3 + HO.SO^3 + 2HO$).
18. Bisulphate of soda ($NaO,SO_3 + HO,SO_3 + 3HO$).
19. Zweifach schwefelsaures Natron, Wasserhaltiges ($NaO,SO_3 + HO,SO_3$).
20. Bisulphate of soda ($NaO,HO,2SO_3$).
21. Bisulfate de soude ($NaO.SO^3 + HO.SO^3 + 2HO$).
22. Bisulphate de soude.
23. Hydro-monosodic sulphate (hydrated bisulphate of soda) ($NaHSO_4$).
24. Bisulfate de soude.
25. Saures schwefelsaures Natron.
26. Sodium and hydrogen sulphate, or acid sodium sulphate ($2SO_4NaH.3OH_2$, or $SO_4Na_2.SO_4H_2.3OH_2$).
27. Hydrosodic sulphate ($NaHSO_4$).
28. Sulfate acide de sodium (SO_4NaH).
29. Bisulphate of soda ($Na_2O,H_2O,2SO_3$).
30. Mononatrium Sulfat, oder halbgesättigtes saures schwefelsaures Natrium.
31. Saures schwefelsaures Natron $SO_2\left\{\begin{matrix}ONa\\OH\end{matrix}\right.$
32. Sodium and hydrogen sulphate, or acid sodium sulphate (see 26).
33. Hydric sodic sulphate (acid sul-

phate of sodium or bisulphate of soda) ($NaHSO_4$).
34. Hydrogen sodium sulphate ($NaH SO_4$).
35. Hydric sodic sulphate (SO_2HoNao).
36. Acid sodium sulphate $SO_2\left(\begin{cases}OH\\ONa\end{cases}\right)$

IV.

1. —
2. See Table III.
3. " "
4. " "
5. " "
6. Anhydrous bisulphate of soda ($S + 2s'$).
7. Bisulphas natricus $\dddot{Na}\,\ddot{S}_2$.
8. Anhydrous bisulphate of soda ($S + 2s'$).
9. —
10. Zweifach schwefelsaures Natron ($NaO, 2SO_3$).
11. Saures (doppelt) schwefelsaures Natron, das wasserleere Salz.
12. —
13. Schwefelsaures Natron, zweifach saures wasserfreies Salz.
14. —
15. (Not specially named.)
16. Anhydrous bisulphate (a true bisulphate).
17. Un véritable bisulphate ($NaO.2SO_3$).
18. Anhydrous bisulphate of soda ($NaO, 2SO_3$).
19. Zweifach schwefelsaures Natron, wasserfreies Salz ($NaO,2SO_3$).
20. Bisulphate of soda, the anhydrous salt.
21. Un véritable bisulphate ($NaO.2SO^3$).
22. —
23. Anhydrosulphate of sodium or anhydrous bisulphate of sodium ($Na_2S_2O_7 = Na_2SO_4,SO_3 = Na_2O, 2SO_3$) 1875.
24. Disulfate de soude.
25. —
26. Anhydro bisulphate (SO_4Na_2,SO_3).
27. Sodic disulphate ($Na_2S_2O_7$).
28. Anhydrosulfate.
29. —
30. Neutrales Kalium Pyrosulfat.
31. Dischwefelsaures Natron

$$\left(O\begin{cases}SO_2ONa\\SO_2ONa\end{cases}\right)$$

32. Pyrosulphate ($Na_2S_2O_7$ or Na_2SO_4, SO_3).
33. Sodic pyrosulphate ($Na_2S_2O_7$).
34. Sodium disulphate ($Na_2S_2O_7$).
35. Sodic pyrosulphate ($S_2O_5Nao_2$).
36. Sodium disulphate $\left(O\begin{cases}SO_2ONa\\SO_2ONa\end{cases}\right)$.

V.

1. (Alkaline chromats.)
2. Chromate of potash [red colour].
3. Bichromate of potash.
4. (Not distinguished from chromates.)
5. Bichromate of potash.
6. Bichromate of potassa ($2Chr' + P$).
7. Bichromas kalicus ($\dot{K}\dddot{C}r_2$).
8. Bichromate of potassa ($2Chr' + P$).
9. Bichromate of potash ($KO,2CrO_3$).
10. Not mentioned.
11. " "
12. Zweifach chromsaures Kali.
13. Doppeltsaures od. rothes chromsaures Kali ($KO,2CrO_3$), 1859.
14. —
15. Bichromate of potash ($KO + 2CrO_3$).
16. Bichromate of potash ($KO,2CrO_3$), 1858.
17. Bichromate de potasse.
18. Bichromate of potassa ($KO,2CrO_3$).
19. Zweifach od. rothes chromsaures Kali ($KaO,2CrO_3$).
20. Bichromate of potash ($KO,2CrO_3$).
21. Bichromate de potasse.
22. —
23. Acid chromate of potassium, dichromate of potassium, or bichromate of potash ($K_2O.2CrO_3 = K_2CrO_4,CrO_3$), 1863. Potassium dichromate ($K_2O.2CrO_3$), 1872.
24. Dichromate de potasse.
25. Saures chromsaures Kali.
26. Potassium bichromate or anhydrochromate ($2CrO_3,K_2O$, or CrO_4K_2, CrO_3).
27. Potassic dichromate ($K_2Cr_2O_7$).
28. Bichromate de potasse ($K_2O,2CrO_3$).
29. Bichromate of potash ($K_2O,2CrO_3$).
30. Kalium dichromat.
31. (Neutrales) Dichromsaures Kali. $\left(O\begin{cases}CrO_2OK\\CrO_2OK\end{cases}\right)$.
32. Potassium bichromate or anhydrochromate ($2CrO_3,K_2O$, or CrO_4K_2, CrO_3).
33. Potassic dichromate, pyrochromate, or anhydrochromate ($K_2O,2CrO_3$, or $K_2Cr_2O_7$).
34. Potassium dichromate, or bichromate of potash ($K_2Cr_2O_7$).
35. Dipotassic dichromate $\left(\begin{cases}CrO_2Ko\\O\\CrO_2Ko\end{cases}\right)$
36. Potassium dichromate.

VI.

1. —
2. —
3. —
4. —
5. —
6. —
7. —
8. —
9. Terchromate of potash ($KO,3CrO_3$).
10. —
11. —
12. Dreifach chromsaures Kali.
13. Dreifach chromsaures Kali ($KO, 3CrO_3$).
14. —
15. —
16. Terchromate of potash ($KO,3CrO_3$) [1858].
17. —
18. —
19. Dreifach chromsaures Kali ($KaO, 3CrO_3$).
20. Terchromate of potash ($KO,3CrO_3$).
21. —
22. —
23. Hyperacid chromate or trichromate of potassium ($K_2O,3CrO_3$ or $K_2CrO_4,2CrO_3$ [1863], potassium trichromate ($K_2O,3CrO_3$) [1872].
24. —
25. —
26. Potassium trichromate ($3CrO_3,K_2O$, or $CrO_4K_2,2CrO_3$)
27. —
28. —
29. Terchromate of potash ($K_2O,3CrO_3$),
30. Kalium trichromat.
31. —
32. Potassium trichromate ($3CrO_3,K_2O$, or $CrO_4K_2,2CrO_3$).
33. Potassic trichromate ($K_2O,3CrO_3$).
34. Potassium trichromate ($K_2Cr_3O_{10}$).
35. Dipotassic trichromate $\left\{\begin{array}{l}CrO_2Ko\\O\\CrO_2\\O\\CrO_2Ko.\end{array}\right.$
36. —

VII.

1. —
2. —
3. —
4. —
5. —
6. Bichromate of chloride of potassium.
7. —
8. Bichromate of chloride of potassium.
9. Bichromate of chloride of potassium ($KCl+2CrO_3$).
10. —
11. —
12. Chromsäure und Chlorkalium ($K\cancel{Cl}+2\dddot{C}r$).
13. Zweifach chromsaure Chlorkalium, chlorchromsaure Kali ($K\cancel{Cl},2CrO_3$ oder $KO,CrO_3.CrO_2\cancel{Cl}$ oder $3(KO.CrO_3)+(Cr\cancel{Cl}_3.2CrO_3)$.
14. —
15. ($KCl,+2CrO_3$).
16. Bichromate of chloride of potassium ($KCl+2CrO_3$).
17. Bichrômate de chlorure de potassium, or chlorochrômate de potasse ($KCl.2CrO^3$).
18. —
19. Zweifach chromsaures Chlorkalium ($KaCl,2CrO_3$).
20. Bichromate of chloride of potassium ($KCl,2CrO_3$).
21. Bichrômate de chlorure de potassium, or chlorochrômate de potasse.
22. —
23. Chromochloride of potassium, 1863. Potassium chromatochloride, 1872. Potassium chlorochromate, 1875 and 1879 (KCl,CrO_3).
24. —
25. —
26. —
27. —
28. Bichromate de chlorure de potassium.
29. —
30. —
31. Chlorchromsaures Kali $\left(CrO_2{}^{Cl}_{OK}\right)$.
32. —
33. Dichromate of chloride of potassium, or potassic chlorochromate (KCl, CrO_3 ?).
34. Potassium chlorochromate ($KCrO_3Cl$).
35. —
36. Potassium chlorchromate.

VIII.

1. Nitrat of lead.
2. Nitrate of lead.
3. Subnitrate of lead.
4. Subnitrate of lead.
5. Dinitrate of lead.
6. Dinitrate of lead ($2PL+n'$).
7. Nitras biplumbicus ($Pb^2\dddot{N}_2$).

8. Dinitrate of lead ((2PL + n′).
9. Bibasic nitrate of lead ($PbO,NO_5 + PbO$).
10. —
11. —
12. Basisch salpetersaures Bleioxyd ($\dot{P}b\ddot{\ddot{N}}$).
13. Zweifach basisch salpetersaures Bleioxyd ($2PbO,\cancel{N}O_5$, or $2PbO,\cancel{N}O_5.\cancel{H}O$).
14. —
15. Basic salt, containing two atoms of oxide of lead united to one of nitric acid.
16. Bibasic nitrate of lead ($PbO,NO_5 + PbO$).
17. Sous-azotate de plomb; azotate bibasique ($2PbO.NO^5 + HO$).
18. Basic nitrate.
19. Halbsaures Salz (PbO,HO,PbO,NO_5).
20. Dinitrate of lead ($2PbO,NO_5$).
21. (See 17).
22. —
23. Basic nitrates of lead; diplumbic nitrate.
24. Azotate basique de plomb $\left(\cancel{Pb}''\begin{cases}\Theta Az\Theta_2\\ \Theta H\end{cases}\right)$.
25. —
26. Basic nitrate.
27. Plumbic hydronitrate ($PbNO_3HO$).
28. Azotate diplombique $(AzO_3)_2Pb,PbO$ or parazotate, $(Az_2O_7)Pb_2$, or orthoazotate $(AzO_4)'''Pb''\bar{H}$.
29. —
30. Halbgesättigt hydratisch basisch Salpetersauresblei.
31. Basisches Salz $\left(\begin{matrix}NO_2\\H\end{matrix}\right\}O_2Pb\Big)$.
32. Basic nitrate.
33. Dibasic plumbic nitrate ($Pb2NO_3, PbH_2O_2$).
34. Basic nitrate, $Pb(NO_3)OH$.
35. Plumbic nitrate hydrate, $NO_2(OPb''Ho)$.
36. Basic salt.

IX.

1. Submuriat of lead.
2. Submuriate of lead.
3. Submuriate of lead.
4. —
5. —
6. —
7. —
8. Oxychloride of lead.
9. Bibasic chloride of lead ($PbCl + 2PbO$), Tribasic ($PbCl + 3PbO$).
10. —
11. —
12. —
13. Einfach-, zweifach-, &c. basisches Chlorblei ($PbCl + PbO$), &c.
14. —
15. —
16. Oxychloride of lead.
17. Oxychlorure.
18. —
19. Basische Bleichloride, Oxychlorid, Bisoxychlorid, &c. ($PbO,PbCl, 2PbO,PbCl$, &c.)
20. Oxychlorides of lead ($PbO,PbCl$, &c.)
21. Oxychlorure.
22. —
23. Oxychlorides (Pb_2Cl_2O or $PbCl_2PbO$, &c.), 1881, III. Supp.
24. Oxychlorures de plomb.
25. —
26. Oxychlorides $PbCl_2,PbO$, &c.)
27. Basic plumbic chlorides ($Pb_2OCl_2, Pb_3O_2Cl_2$, &c.)
28. —
29. Oxychlorides of lead ($PbCl_2,PbO$, &c.)
30. Diplumboxydchlorür; Triplumbdioxydchlorür, &c.
31. Basische Salze.
32. Oxychlorides ($PbCl_2,PbO$, &c.)
33. Oxychlorides of lead ($PbO,PbCl_2$, &c.)
34. Basic chlorides ($PbCl_2 + PbO$, &c.)
35. Oxychlorides.
36. Oxy- or basic chloride.

X.

1. —
2. Subnitrate of bismuth.
3. Subnitrate of bismuth.
4. —
5. Tetartonitrate of bismuth.
6. Hydrated subnitrate of bismuth.
7. —
8. Hydrated subnitrate of bismuth.
9. Subnitrate of bismuth ($HO,NO_5 + 3BiO$).
10. Salpetersaures Wismuthoxyd, einfach. Basisch salpetersaures Wismuthoxyd ($BiO_3,NO_5 + Aq$).
11. Basisch salpetersaures Wismuthoxyd; Bismuthum Subnitricum ($N_2O_5,BiO + 3BiO,Aq.N_2O_5,BiO + 2BiO$).
12. Verbindung von salpetersaurem Wismuthoxyd mit Wismuthoxydhydrat ($Bi\ddot{\ddot{N}} + 3\dot{B}i\dot{\cancel{H}}$).

13. Basisch salpetersaures Wismuthoxyd, drittelsaures salpetersaures Wismuthoxyd.
14. Basisch salpetersaures Wismuth.
15. A basic salt $(BiO_3 + NO_5)$.
16. Subnitrate of bismuth $(BiO_3,NO_5 + HO)$.
17. Sous-azotate de bismuth.
18. Basic nitrate of teroxide of bismuth $(BiO_3,NO_5 + 2HO)$.
19. Drittelsaures Salz $(BiO_3,NO_5 + 2HO)$, Bisoxynitrat $(2(BiO_3,3HO)BiO_3,3NO_5)$.
20. Subnitrate of bismuth $(9HO,4NO_5, + 5BiO_3)$.
21. Sous-azotate de bismuth.
22. —
23. A basic nitrate $(BiNO_4,H_2O$ or $Bi_2O_3,N_2O_5,2H_2O)$.
24. Sous-azotate.
25. —
26. Basic nitrate $(Bi_2O_3,N_2O_5,2OH_2$, or $Bi''(NO_3)_3,Bi_2O_3,3OH_2)$.
27. —
28. Azotate basique de bismuth $(Bi'''(AzO_4) + H_2O$ or $(BiO)AzO_3 + H_2O)$.
29. Basic nitrate of bismuth, also called trisnitrate of bismuth (Bi_2O_3, N_2O_5,H_2O).
30. Wismuthnitrat. $Bi(ONO_2)(OH)_2$.
31. Basisches salpetersaures Wismuthoxyd $\left(\begin{matrix}N & \\ & H_2^2\end{matrix}\right\}O_3Bi$ or $NO_2OBiO + H_2O)$.
32. Basic nitrate (see 26).
33. Bismuthous subnitrate $(Bi_2O_3, 2HNO_3)$.
34. Basic bismuth nitrate, $Bi(OH)_2NO_3$.
35. Bismuthous nitrate dihydrate, $NO_2(Bi''Ho_2O)$.
36. Basic bismuth nitrate, $Bi(OH)_2NO_3$.

XI.

1. —
2. —
3. —
4. —
5. A subsalt.
6. A compound of oxide of bismuth with chloride.
7. —
8. (See 6.)
9. A subsalt $(BiCl + 2\,BiO + HO)$
10. Wismuthoxyd-chlorwismuth. Wismuthoxychlorür. Basisch salzsaures Wismuthoxyd $(BiCl_3, 2BiO_3)$.
11. Basisches Salz.
12. $(BiCl + 2\dot{B}i\dot{\cancel{H}})$.
13. Wismuth Bisoxychlorid. Zweifachbasisches Wismuth Chlorid $(Bi_2\cancel{Cl}O_2$ oder $Bi_2\cancel{Cl}_3 + Bi_2O_3)$.
14. —
15. Oxychloride of bismuth $(BiCl_3 + 2BiO_3 + 3HO)$.
16. Oxychloride of bismuth $(BiCl_3, 2BiO_3)$.
17. Oxychlorure de bismuth $(Bi_2Cl_3 + 2(Bi_2O_3 + 3HO)$.
18. —
19. Bisoxychlorid, zweifach basisches Salz $(2BiO_3,BiCl_3)$.
20. Oxychloride of bismuth $(BiCl_3, 2BiO_3)$.
21 (See 17.)
22 —
23. Oxychloride of bismuth $(BiOCl)$, 1863. Bismuthyl chloride $(BiOCl)$, 1879. Supp. III.
24. Oxychlorure $(BiOCl)$.
25. Basisches Chlorwismuth.
26. Oxychloride $(BiClO)$.
27. Bismuth oxychloride $(BiOCl)$.
28. Oxychlorure de bismuth $(BiOCl$ or $Bi_2O_3,BiCl_3)$.
29. Oxychloride of bismuth, $2(BiCl_3, Bi_2O_3),H_2O$.
30. Wismuthoxychlorür.
31. Basisches Chlorwismuth, Wismuthoxychlorid $(BiOCl)$.
32. Oxychloride $(BiClO)$.
33. Bismuthous oxychloride, $2(BiCl_3 Bi_2O_3),OH_2$ or $BiOCl$.
34. Bismuth oxychloride $(BiOCl)$.
35. Bismuthous oxychloride $(BiOCl)$.
36. Basic bismuth chloride. (Bismuth oxychloride.)

XII.

1. Oxysulphat of mercury.
2. Suboxysulphate of mercury.
3. Neutral persulphate of mercury.
4. Suboxysulphate of mercury.
5. Disulphate of mercury.
6. A sub-salt.
7. —
8. A sub-salt.
9. $(HgO.SO_3 + 2HgO)$.
10. Schwefelsaures Quecksilberoxyd, Drittel $(3HgO.SO_3)$.
11. Basisches schwefelsaures Quecksilberoxyd $(3HgO.SO_3)$.
12. Basisches schwefelsaures Quecksilberoxyd.
13. Basisch schwefelsaures Quecksilberoxyd $(3HgO.SO_3)$.
14. Basisches schwefelsaures Quecksilberoxyd.
15. Basic sulphate $(3HgO + SO_3)$.
16. Sub-sulphate.
17. Sel basique $(3HgO.SO^3)$.

18. A basic salt ($3HgO.SO_3$).
19. Drittelsaures Salz ($3HgO.SO_3$).
20. A sub-salt ($3HgO.SO_3$).
21. Sel basique ($3HgO.SO^3$).
22. —
23. Basic sulphate of mercury ($3HgO.SO_3 = HgSO_4.2HgO$).
24. Sel basique $\left.\left(\left.\begin{matrix}\mathrm{S\Theta}^{2''}\\ \mathrm{Hg}\\ \mathrm{Hg}\\ \mathrm{Hg}\end{matrix}\right\}\begin{matrix}\Theta\\ \Theta\end{matrix}\right)''\right\}\Theta^2$
25. —
26. A basic salt ($3HgO.SO_3$).
27. A basic salt (Hg_3SO_6).
28. Sulfate trimercurique($SO_4Hg,2HgO$).
29. A basic sulphate ($HgO.SO_3.2HgO$).
30. Drittelgesättigtes Mercuridsulfat.
31. Basisches Salz ($SO_2O_2Hg + 2HgO$).
32. A basic salt ($3HgO.SO_3$).
33. A basic salt ($HgSO_4.2HgO$).
34. A basic salt (Hg_3SO_6).
35. Trimercuric sulphate ($\mathrm{SH\overset{''}{g}o_3}$).
36. Basic sulphate ($SO_2.O_2Hg + 2HgO$).

XIII.

1. —
2. —
3. —
4. —
5. —
6. —
7. —
8. Chlorosulphuret of mercury (hg + 2C) + 2(hg + 2S).
9. Chloride and sulphuret of mercury ($HgCl + 2HgS$).
10. Chlorquecksilber-Schwefelquecksilber, oder Chlor- und Schwefelquecksilber ($2HgS,HgCl$).
11. Schwefelbasisches Quecksilberchlorid (Berzelius' nomenclature) ($HgCl_2 + 2HgS$).
12. Quecksilberschwefelchlorid ($HgCl, + 2HgS$).
13. —
14. —
15. Chlorosulphuret ($HgCl + 2HgS$).
16. Sulphochloride of mercury ($HgCl, 2HgS$).
17. $HgCl + 2HgS$.
18. —
19. Quecksilbersulphuretochlorid (Quecksilberchlorosulphuret) ($2HgS,HgCl$).
20. —
21. (See No. 17.)
22. —
23. Sulphochloride of mercury ($Hg_3S_2Cl_2$).
24. —
25. —
26. —
27. Mercuric sulphochloride ($Hg_3S_2Cl_2$).
28. Sulfochlorure mercurique ($2HgS, HgCl_2$).
29. Chlorosulphide of mercury ($HgCl_2 2HgS$).
30. Mercuridthiochlorür.
31. —
32. —
33. —
34. ($2HgS,HgCl_2$).
35. Trimercuric disulpho-dichloride $\left(\begin{matrix}\mathrm{HgCl}\\ \mathrm{HgCl}\end{matrix}\mathrm{Hg}''_{\mathrm{s}}\right)$
36. —

XIV.

1. —
2. —
3. —
4. —
5. Sulphoantimoniate.
6. —
7. Sulphostibias natricus ($\acute{\mathrm{Na}}\ \overset{'''}{\mathrm{Sb}}_2$).
8. —
9. —
10. Fünffachschwefelantimonnatrium.
11. Antimonpersulphid-Natrium (Sulphostibias natricus cum aqua) ($Sb_2S_5, NaS + 12Aq$).
12. Natrium antimon Sulphid ($3\ NaS + SbS_5$).
13. Antimonpersulphid-Natrium. Antimonpersulphid - schwefelnatrium, &c., &c. ($Sb_2S_5.NaS$).
14. —
15. —
16. Sulphantimoniate ($3NaS.SbS_5$).
17. Sulfantimoniate de sulfure de Sodium ($3NaS.Sb_2S_5$).
18. —
19. Natrium sulphantimoniat ($3NaS, SbS_5$).
20. Sulphantimoniate of sodium ($3NaS, SbS_5$).
21. Sulfantimoniate de sulfure de sodium ($3NaS.Sb_2S_5$)
22. —
23. Sulphantimonate of sodium (Na_3SbS_4 or $3Na_2S.Sb_2S_5$).
24. —
25. —
26. Sulphantimoniates ($Sb_2S_5,3M_2S$ or SbS_4M_3).
27. Sodic sulphantimoniate (SbS_4Na_3).
28. Sulfo-antimoniate de sodium ($SbS_4 Na_3$).
29. Sulphantimoniate.
30. Natriumthioantimonat (Na_3SbS_4).

31. SbS_4Na_3, or $(SbS)\ S_3Na_3$.
32. Sodium-sulphantimonate.
33. Trisodic sulphantimoniate (Na_3SbS_4).
34. Sodium thioantimonate (Na_3SbS_4).
35. Trisulphosodic sulphantimonate ($Sb S''Nas_3$).
36. —

XV.

1. Fluat of potass and silica.
2. Fluate of potash and silica.
3. Fluosilicate of potash.
4. Silico-fluate.
5. Fluosilicate of potash.
6. Silicofluoride of potassium ($po + 2Si + 3f$).
7. —
8. Silicofluoride of potassium ($po + 2Si + 3f$).
9. Double fluoride of silicon and potassium ($2SiF_3,3KF$).
10. Fluor-siliciumkalium (KF,SiF_2).
11. Fluorsiliciumkalium. Kieselfluorkalium ($3KF_2,2SiF_6$).
12. Fluorkiesel Kalium.
13. Kalium-Kieselfluorid ($3KF,2SiF_3$).
14. —
15. Fluosilicate of potassium, silicofluoride of potassium ($SiF_2 + KF$).
16. Double fluoride of silicon and potassium ($2SiF_3,3KF$).
17. Hydrofluosilicate de potasse ($3KFl, 2SiFl_3$).
18. Double fluoride of silicium and potassium ($3KF,SiF_3$).
19. Kieselfluorkalium. Fluorkieselkalium ($3KaFl,2SiFl_3$, oder $KaFl,SiFl_2$).
20. Silicofluoride of potassium (KF, SiF_2).
21. Hydrofluosilicate de potasse ($3KFl, 2SiFl_3$).
22. —
23. Silicofluoride of potassium. Potassic silicofluoride ($2KF,SiF_4$).
24. Fluorure double de silicium et de potassium.
25. Kieselfluorkalium.
26. Double fluoride of silicium and potassium ($2KF,SiF_4$).
27. Potassic fluosilicate (K_2SiF_6).
28. Fluosilicate de potassium.
29. Silicofluoride of potassium ($2KF, SiF_4$).
30. Metallsilicofluorüre.
31. Kieselfluormetalle (SiF_4,MF_2).
32. Double fluoride of silicium and potassium ($2KF,SiF_4$).
33. Potassic silicofluoride.
34. Silicofluoride. potassium fluosilicate (K_2SiF_6).
35. Potassic silicofluoride ($SiF_6K_2 = Si F_4,2KF$).
36. Potassium fluosilicate.

XVI.

1. Muriat of platinum and potass.
2. Muriate of platinum and potash.
3. —
4. —
5. Bichloroplatinate of potassium.
6. Platino-bichloride of potassium ($(pl + 2c) + (po + c)$).
7. —
8. Platino-bichloride of potassium ($(pl + 2c) + (po + c)$).
9. Chloride of platinum and potassium ($KCl + PtCl_2$).
10. Zweifach Chlorplatinkalium ($KCl + PtCl_2$).
11. Kaliumplatinchlorid ($KCl_2 + PtCl_4$).
12. Kaliumplatinchlorid.
13. Kalium-platinchlorid ($KCl + PtCl_2$).
14. Platinchlorid-chlorkalium.
15. Double salt of bichloride of platinum with chloride of potassium ($KCl + PtCl_2$).
16. Chloroplatinate of potassium ($KCl, PtCl_2$).
17. Chlorure double de platine et de potassium ($PtCl_2 + KCl$).
18. Bichloride of platinum and chloride of potassium ($PtCl_2,KCl$).
19. Kalium-platinchlorid. Kalium-chloroplatinat ($KaCl,PtCl_2$).
20. Double chloride of platinum and potassium ($KCl,PtCl_2$).
21. Chlorure double de platine et de potassium ($PtCl_2 + KCl$).
22. —
23. Chloroplatinate of potassium, 1866. potassium platinochloride ($K_2Pt Cl_6$). Supp. I. 1872.
24. Chlorure double de platine et de potassium.
25. Kaliumplatinchlorid.
26. Potassium platinochloride ($2KCl, PtCl_4$).
27. —
28. Chloroplatinate de potassium.
29. Platinochloride of potassium ($2KCl, PtCl_4$).
30. Kaliumplatinchlorid.
31. Kaliumplatinchlorid ($2KCl,PtCl_4$).
32. Potassium platinochloride or chloroplatinate ($2KCl,PtCl_4$).

33. Potassic platinic chloride.
34. Potassium platinichloride or chloroplatinate (K_2PtCl_6).
35. Potassic platinic chloride ($PtCl_4$, 2KCl).
36. Potassium chlorplatinate.

XVII.

1. —
2. —
3. —
4. —
5. —
6. Cyanuret of platinum and potassium.
7. —
8. Cyanuret of platinum and potassium.
9. Platino-cyanide of potassium (K, $PtCy_2 + 3HO$).
10. Einfach-cyanplatinkalium (KCy, PtCy).
11. —
12. Kalium Platincyanür (KЄy, + PtЄy + $3\dot{\text{H}}$).
13. Kalium Platincyanür (KЄy + PtЄy + 3ĦO).
14. —
15. Platinocyanide of potassium (PtCy + KCy or K,Cpty).
16. Platinocyanides (MCy,PtCy).
17. Cyanure double de platine et de potassium (KCy + PtCy + 3HO).
18. —
19. Kaliumplatincyanür (KaCy,PtCy + 3HO).
20. —
21. Cyanure double de platine et de potassium (KCy + PtCy + 3HO).
22. —
23. Platinocyanide of potassium ($K_2PtCy_4 = 2KCy,PtCy_2$), 1866. Potassio platinous cyanide (K_2PtCy_4). Supp. I. 1872.
24. —
25. —
26. —
27. —
28. Plantinocyanure de potassium, ($PtCy^4$) $K^2 + 3H^2O$.
29. —
30. Kaliumplatincyanür.
31. Kaliumplatincyanür ($2KCy,PtCy_2$).
32. —
33. —
34. Potassium platinocyanide, $K_2Pt(CN)_4 + 12H_2O$.
35. —
36. Potassium platinous cyanide.

XVIII.

1. —
2. —
3. —
4. —
5. —
6. —
7. —
8. —
9. Acetate and arsenite of copper, CuO, $(C_4H_3O_3) + 3\ (CuO.AsO_3)$.
10. Essigarsenigsaures Kupferoxyd, $3(CuO,AsO_3) + C_4H_3CuO_4$.
11. Essigsaures Kupferoxid und Arsenigsaures Kupferoxid, A,CuO $+ 3(AsO_3$, CuO).
12. Arsenichtsaures und essigsaures Kupferoxyd, ($\dot{\text{Cu}}\bar{\text{A}} + 3\dot{\text{Cu}}^2\ddot{\text{As}}$).
13. Arsenigessigsaures Kupferoxyd.
14. —
15. Compound of acetate of copper, and arsenite of copper, CuO.$\bar{\text{A}}$ $+ 3(HO.2CuO + AsO_3)$.
16. Acetate and arsenite of copper, CuO, $(C_4H_3O_3) + 3\ (CuO.As_2O_3)$.
17. Une combinaison, CuO. $C_4H_3O_3$ $+ 3(2\ CuO.AsO_3)$.
18. —
19. Eine Verbindung, $CuO,AcO_3 + 3(2CuO,AsO_3)$.
20. $CuO,C_4H_3O_3 + 3\ (CuO,AsO_3)$.
21. $CuO,C_4H_3O_3 + 3\ (2CuO,AsO_3)$.
22. —
23. Aceto-arsenite of copper $(C_2H_3O_2)_2$ Cu'', $3\ (AsO_2)_2\ Cu''$ or $C_4H_6O_3.\ Cu''O + 3\ (As_2O_3.Cu''O)$.
24. —
25. —
26. —
27. Cupric acetoarsenite, $Cu(AsO_2)$ $(C_2H_3O_2)$.
28. Un acétoarsénite.
29. —
30. Arsenigessigsaures Kupfer, $Cu_2(OAsO)_3\ (OC_2H_3O)$.
31. —
32. —
33. Cupric arsenite and acetate, $3CuAs_2O_4$. Cu $(C_2H_3O_2)_2$.
34. Copper acetoarsenite, $3CuAs_2O_4$ + Cu $(C_2H_3O_2)_2$.
35. —
36. Double compound.

Report of the Committee, consisting of Professors ODLING, HUNTINGTON, *and* HARTLEY, *appointed to investigate by means of Photography the Ultra-Violet Spark Spectra emitted by Metallic Elements, and their combinations under varying conditions. Drawn up by* Professor W. N. HARTLEY, *F.R.S.* (*Secretary.*)

THE last Report of this Committee was presented at the Southport meeting of the British Association; since then an investigation in detail has been prosecuted of the changes observable in photographs of the spectra of the metals when a series of solutions of definite strengths is examined. It had previously been shown that solutions containing the same element in different proportions emit variations of the same spectrum, the lines differing in number, length, and intensity; and the converse—namely, that under the same spark conditions similar solutions of the same strength always emit the same spectrum. Furthermore, I have shown the invariable character of the cadmium, tin, lead, and magnesium lines by observations made on about five thousand photographs, including not fewer than two hundred examples of other metals. The reason of this arises from the fact that unless the spark be almost at the highest temperature attainable, its emissive power is insufficient to affect the photographic plate in the usual period of exposure; it follows from this that when a condenser of constant capacity is in circuit, variable conditions such as may be introduced by the electrodes being near together or far apart, or by the use of a large or small coil, do not affect the result. Sparks are shortened and the character of the spectra is greatly altered by the use of a coil with a stout secondary wire, an instrument introduced and employed by M. Eugène Demarçay. The use of an instrument of this kind is not well adapted to the photographic method of working, because the nature of the sparks is such that the graphite electrodes are rapidly burnt away and the sparks are very short.

For the examination of solutions chlorides are generally employed, but sulphates and nitrates are also used. The electrodes are nearly always of graphite ('Phil. Trans.' p. 52, Part I. 1884); sometimes gold, copper, or platinum electrodes are required for special purposes, wires of the metal being twisted into wicks.

The solutions examined generally contained 1 per cent., $\frac{1}{10}$th, $\frac{1}{100}$th, and $\frac{1}{1000}$th of metal. It is seldom that more than three or four lines are visible in solutions of the latter dilution, and the rapidly diminishing number of lines in solutions weaker than $\frac{1}{10}$th per cent. is very striking. In the following tables the spectra corresponding to various solutions are given, and attention is particularly directed to the copper, silver, and tin spectra as illustrating this point. In many spectra it is impossible to predict the line or lines which will be found to be the most persistent. It is also noticeable that the alteration of lines consequent on the dilution of solutions is variable in character with different lines in the same spectrum. Generally speaking, long lines shorten until they disappear, sometimes they become attenuated before they shorten, and in other cases they attenuate until they fade away altogether.

The calcium lines H and K attenuate considerably before they shorten, while the lines of copper with wave-lengths 3273·2 and 3246·9, and of silver, 3382·3 and 3280·1, attenuate and fade almost away before shortening.

Several examples could be quoted of the analysis of minerals made by the spectroscope, the metallic constituents being estimated quantitatively with exactitude and great facility. In some cases the results obtained by the spectroscope inspire greater confidence than those made by ordinary methods.

The descriptive tables which follow are intended to be used with maps drawn to the scale of wave-lengths, and to a scale of actual measurements taken from photographs, so that the lines may be readily identified. The scale numbers given in the tables in hundredths of an inch refer to photographs such as those published in the 'Journal of the Chemical Society' ('Trans.' vol. xli. p. 90, 1882), from which actual measurements may be taken with an ivory scale.

The limit of sensitiveness of the spectrum reaction is perhaps the greatest in the case of magnesium; one part of the metal in 10,000 millions of solution is easily detected by the appearance of the lines with wave-lengths 2801·6 and 2794·1 attenuated and shortened. By increasing the strength of the spark the sensitiveness may be magnified 10,000 fold.

It was shown in the Report presented in 1883 how spectrum observations may be applied to determining the atomic weight of an element. Taking into account the spectrum of beryllium, this metal could find no place among the triad elements, but naturally took a position at the head of the dyad group. According to the periodic law its atomic weight would thus have the value 9. This view was opposed at the time, but it is satisfactory to learn that it has since been completely confirmed by the experimental work of Messrs. Nilson and Petterson and Dr. Humpidge.

The Zinc Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
108·49	3344·4	3344·4	3344·4
113·75	3301·7	3301·7	3301·7
116·30	3281·7	3281·7	3281·7
145·69	3075·6	3075·6	
194·98	2800·1	2800·1 ?	
252·31	2557·3	2557·3	
267·95	2501·5	2501·5	

The Thallium Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
64·55	3775·6	3775·6	3775·6
88·7	3518·6	3518·6	
143·0	3091·0	3091·0	
172·21	2917·7		
201·87	2767·1	2767·1	2767·1
259·86	2530·0	2530·0	
335·27	2299·3	2299·3	

The Cadmium Spectrum.

Scale numbers	Wave-lengths			
	1 per cent.	0·1 per cent.	0·01 per cent.	0·001 per cent.
Hundredths of an inch				
79·37	3612·0	3612·0	3612·0	
79·68	3609·6	3609·6	3609·6	
94·30	3466·7	3466·7	3466·7	
94·50	3465·2	3465·2	3465·2	
101·45	3402·8	3402·8		
119·0	3260·2			
205·87	2747·7	2747·7		
248·24	2572·3	2572·3		
326·8	2321·6			
329·85	2313·5	2313·5	2313·5	
339·25	2288·8	2288·8	2288·8	
348·15	2265·8	2265·8	2265·8	2265·8
377·48	2196·4			
400·2	2146·8			

The Aluminium Spectrum.

Scale numbers	Wave-lengths			
	1 per cent.	0·1 per cent.	0·01 per cent.	0·001 per cent.
Hundredths of an inch				
49·85	3960·9	3960·9	3960·9	3960·9 ?
51·16	3943·4	3943·4	3943·4	3943·4 ?
The air-lines contiguous to the above are very strong, hence it is a little doubtful whether they are present in the spectrum of a solution so dilute as 0·01 per cent.				
70·02	3713·4			
71·05	3701·5			
79·17	3612·4	3612·4	3612·4	
80·5	3601·1	3601·1	3601·1	
82·07	3584·4			
142·86	3091·8	3091·8	3091·8	3091·8
144·5	3081·2	3081·2	3081·2	3081·2
148·5	3056·6			
191·76	2815·3	2815·3	2815·3	2815·3
226·3	2659·3	2659·3		
228·26	2651·2	2651·2		
249·66	2566·9	2566·9		
308·55	2373·3			
309·0	2372·0			
309·6	2370·2			
309·94	2367·2			
310·62	2364·5			

The line with wave-length 3584·4 is both *much longer* and *stronger* than either 3612·6 or 3601·2, yet it is not so persistent. From appearing as a strong line it disappears rather suddenly.

The line with wave-length 2815·3 is the strongest in this spectrum.

Tabular Description of the Spectra characteristic of Solutions containing Magnesium.

Scale numbers	Wave-lengths of the lines visible. Parts of magnesium per 100 of solution								
	10 per cent.	1 per cent.	0·1 per cent.	0·03 per cent.	0·02 per cent.	0·01 per cent.	0·003 per cent.	0·002 per cent.	0·001 per cent.
Hundredths of an inch									
17·46	4480	4480	4480						
59·30	3837·9	3837·9	3837·9	3837·9	3837·9				
59·83	3832·1	3832·1	3832·1	3832·1	3832·1				
60·07	3829·2	3829·2	3829·2						
142·3	3096·2	3096·2	3096·2						
142·85	3091·9	3091·9	3091·9						
143·18	3089·9	3089·9	3089·9						
168·7	2935·9	2935·9	2935·9	2935·9	2935·9	2935·9	2935·9	2935·9	2935·9
170·18	2928·2	2928·2	2928·2	2928·2	2928·2	2928·2	2928·2	2928·2	2928·2
184·63	2851·2	2851·2	2851·2	2851·2	2851·2	2851·2	2851·2	2851·2	2851·2
194·55	2801·6	2801·6	2801·6	2801·6	2801·6	2801·6	2801·6	2801·6	2801·6
195·39	2796·9	2796·9	2796·9	2796·9	2796·9	2796·9	2796·9	2796·9	2796·9
195·95	2794·1	2794·1	2794·1	2794·1	2794·1	2794·1	2794·1	2794·1	2794·1
196·92	2789·6	2789·6	2789·6	2789·6	2789·6	2789·6	2789·6	2789·6	2789·6
198·64	2781·8	2781·8	2781·8	2781·8					
198·96	2780·2								
199·3	2778·7	2778·7	2778·7	2778·7	2778·7	2778·7			
199·61	2776·9								
199·97	2775·5	2775·5	2775·5						

A line may be shortened or weakened, but its wave-length in this table denotes that although it may be changed it is still visible. The numbers bracketed are the wave-lengths of characteristic groups of lines.

The Indium Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
15·88	4510·2	4510·2	
39·91	4101·3	4101·3	
119·31	3257·8		
119·68	3255·5	3255·5	3255·5
151·35	3038·7	3038·7	3038·7
168·00	2940·8	2940·8	
177·34	2889·7	2889·7*	
214·56	2709·3	2709·3	
251·76	2559·5		
332·2	2307	2307	

* This is barely visible.

The Copper Spectrum.

Scale numbers	Wave-lengths			
	1 per cent.	0·1 per cent.	0·01 per cent.	0·001 per cent.
Hundredths of an inch				
113·10	3306·8	3306·8		
115·10	3289·9			
{117·25*	{3273·2	3273·2	3273·2	
{120·7	{3246·9	3246·9	3246·9	3246·9
164·53	2959·5			
190·13	2823·2			
201·36	2769·1	2769·1		
211·8	2721·2			
212·55	2718·4	2718·4		
213·7	2713·0	2713·0		
216·1	2702·7			
216·58	2700·5			
219·37	2688·8	2688·8		
224·7	2666·7			
236·45†	2617·8			
241·1	2599·7			
241·58	2598·3			
255·94	2544·6	2544·6		
260·25	2528·8	2528·8		
261·00	2526·2			
266·77	2506·2	2506·2		
270·91	2491·4			
271·65	2489·1			
272·72	2485·6			
276·45	2473·2			
298·31	2403·3			
299·4	2400·1			
{309·17	{2371·6	2371·6		
{309·57	{2370·1	2370·1		
336·8	2295·0			
343·67	2277·0			
{355·27‡	{2248·2	2248·2		
{355·5	{2247·7	2247·7		
{357·1	{2244·0	2244·0		
{357·32	{2243·5	2243·5		

* This pair of lines differs from all others in the spectrum by not being shortened on dilution, but becoming attenuated till at last they disappear. They remain long lines till the last.

† This is a very fine and very long line.

‡ This group is distinctly seen to be composed of four lines in the photographs of the 1 per cent. solution, and some lines, to the number of four or five, more refrangible than these are visible.

The Silver Spectrum.

Scale numbers	Wave-lengths			
	1 per cent.	0·1 per cent.	0·01 per cent.	0·001 per cent.
Hundredths of an inch				
103·94	3382·3	3382·3	3382·3	
116·45	3280·1	3280·1	3280·1	
168·5	2937·5			
169·3	2933·5	2933·5		
170·17	2928·2	2928·2		
175·02	2901·6			
176·07	2895·6			
180·44	2872·7	2872·7		
191·82	2814·5			
195·03	2798·8			
201·81	2766·4	2766·4		
204·2	2755·5			
214·22	2711·3	2711·3		
226·27	2659·6	2659·6		
227·08	2656·2			
246·3	2579·9			
268·81	2506·0	2506·0		
274·52	2479·9			
275·41	2476·8			
276·41	2473·3	2473·3		
279·92	2462·2			
280·52	2459·8			
282·6	2453·0			
284·38	2447·4	2447·4		
287·46	2437·3	2437·3	2437·3	
290·0	2429·8	2429·8		
293·08	2419·9	2419·9		
295·35	2413·3	2413·3	2413·3	2413·3
295·94	2411·3	2411·3		
297·94	2406·4			
298·85	2404·5			
301·10	2395·7			
302·74	2390·8			
304·07	2386·7			
305·25	2383·6			
307·94	2375·5			
311·70	2364·3			
312·34	2362·3			
313·47	2359·2	2359·2		
313·88	2358·0	2358·0		
323·35	2331·7	2331·7	2331·7	
325·73	2325·3	2325·3	2325·3	
327·37	2320·5	2320·5	2320·5	
328·59	2317·4	2317·4	2317·4	
342·55	2280·7	2280·7		
354·95	2249·9	2249·9		
354·90	2247·6	2247·6	2247·6	
362·86	2230·6			

The Mercury Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
74·6	3662·9		
75·37	3654·4		
77·37	3632·9	3632·9	
137·08	3130·4		
137·95	3124·5	3130·4	
163·37	2966·4	2966·4	
185·45	2846·8		
258·75	2533·8	2533·8	2533·8
364·51	2225·7		

The Tin Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
62·40	3800·3	3800·3	
107·51	3351·8	3351·8	
110·25	3329·9	3329·9	
116·03	3282·9	3282·9	
118·83	3261·6	3261·6	
130·7	3174·3	3174·3	
152·18	3033·0	3033·0	
156·29	3007·9	3007·9	
173·05	2912·0		
176·18	2895·0		
177·8	2886·9		
182·47	2862·0	2862·0	2862·0
184·99	2849·2		
187·01	2833·9	2833·9	
192·3	2812·5	2812·5	
198·28	2784·0		
199·34	2778·8	2778·8	
215·35	2705·8	2705·8	2705·8
224·95	2664·2		
225·98	2660·6		
226·56	2657·9	2657·9	
229·67	2645·4		
230·23	2643·2	2643·2	
233·17	2631·4	2631·4	
242·65	2593·6		
243·10	2591·7		
248·70	2570·5	2570·5	
255·45	2545·6	2545·6	
269·8	2495·0		
273·4	2482·9	2482·9	
289·95	2429·3	2429·3	2429·3
292·37	2421·8	2421·8	
310·11	2368·3		
314·85	2355·0	2355·0	
321·94	2335·3		
328·34	2317·9		
355·83	2247·0		

The Lead Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
42·93	4057·5	4057·5	
67·61	3738·9	3738·9	
72·69	3682·9	3682·9*	
76·8	3639·2	3639·2	
83·31	3572·6	3572·6	3572·6
170·45	2872·2	2872·2†	
188·37	2832·2	2832·2	
190·30	2822·1		
225·41	2662·5	2662·5	
237·48	2613·4	2613·4	
247·08	2576·4		
373·43	2204·3		

The Tellurium Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
103·9	3382·4	3382·4	
116·43	3280·0	3280·0	
117·35	3273·4	3273·4	
120·77	3246 8	3246·8	3246·8
176·24	2894·3		
181·25	2867·7		
183·4	2857·0		
344·1	2386·3	2386·3‡	
304·92	2383·8	2383·8‡	
355·18	2248·0		
355·36	2247·3§		
357·18	2243·3		

The Arsenic Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
183·04	2859·7		
199·22	2779·5	2779·5	
316·6	2350·1		
339·14	2288·9		

This is an exceedingly poor spectrum.

* Barely visible. † Very faint.
‡ These lines appear very distinctly and are continuous in a 1 per cent. solution.
§ The two last lines are faint, 2243·3 exceedingly so.

The Antimony Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
67·63	3739·0		
80·74	3597·8		
90·21	3504·6		
109·36	3336·4		
118·21	3266·6		
120·8	3246·6		
122·87	3231·6		
152·91	3029·0		
179·29	2877·1	2877·1	2877·1
197·05	2789·6	2789·6	
241·65	2597·2	2597·2	2597·2
260·33	2527·6	2527·6	
330·37	2311·8		

The Bismuth Spectrum.

Scale numbers	Wave-lengths		
	1 per cent.	0·1 per cent.	0·01 per cent.
Hundredths of an inch			
63·1	3792·7		
71·63	3695·3		
80·99	3595·7		
89·69	3510·5		
98·4	3430·9		
102·25	3396·7		
146·85	3067·1	3067·1	3067·1
153·75	3023·8	3023·8	
158·98	2992·2	2992·1	
159·67	2988·1		
168·52	2937·5		
175·85	2897·2	2897·2	
183·91	2854·8	2854·8	
185·49	2846·1	2846·1	
294·66	2414·8		

Report of the Committee, consisting of Professor TILDEN, Professor W. RAMSAY, *and* Dr. W. W. J. NICOL (*Secretary*), *appointed for the purpose of investigating the subject of Vapour Pressures and Refractive Indices of Salt Solutions.*

I. *Molecular Volumes of Salt Solutions. Part II.*[1]

THE molecular volumes have been determined of fifty-six solutions, comprising forty-seven salts of potassium, sodium, lithium, strontium, cadmium, cobalt, and nickel, with chlorine, bromine, chloric, carbonic, sulphuric, nitric, orthophosphoric, metaphosphoric, acetic, oxalic, tartaric,

[1] Published in *Phil. Mag.*, 1884.

and citric acids. The previous results were completely confirmed. The law is as follows :—

The molecular volume of a salt in dilute solution is a quantity composed of two constants, one for the metal and another for the salt radical. It follows that the replacement of one metal, or salt radical, by another metal, or salt radical, is always attended by the same volume charge, no matter how they may be combined together.

The presence or absence of *water of crystallization* in one or both of the salts has no effect on the above law; it therefore follows that it has the same volume as the solvent water. *Water of constitution*, however, shows itself in solution by possessing a volume markedly different from that of the rest of the water.

These results point to the presence in solution of what may be termed the anhydrous salt, in contradistinction to the view that a hydrate, definite or indefinite, results from solution; or, in other words, no part of the water in solution is in a position, relative to the salt, different from the remainder.

II. *Saturation of Salt Solutions. Part II.*

It is found that the molecular volumes of a series of solutions of different strengths of the same salt may be satisfactorily expressed by the formula :—

$$\text{M. V.} = 1800 + n\alpha + n^2\beta - n^3\gamma.$$

Where n = number of molecules of salt per 100 H_2O, and α, β, and γ constants depending on the salt,

$$r = n\alpha + n^2\beta - n^3\gamma;$$

and

$$\frac{r}{n} = \alpha + n\beta - n^2\gamma.$$

This last is the mean molecular volume of the salt in solution. The curve is a parabola, and is such that $\frac{\beta}{\gamma} =$ twice the solubility of the salt in question $\therefore \frac{\beta}{2\gamma} =$ solubility; but this is also the apex of the parabola; saturation is therefore reached when the further addition of salt would produce diminution of the mean molecular volume of the molecules already present. The last molecule before saturation, enters into solution with a volume sensibly equal to the mean, as is shown thus :—

$$(n\alpha + n^2\beta - n^3\gamma) - ((n-1)\alpha + (n-1)^2\beta - (n-1)^3\gamma) = \alpha + n\beta - n^2\gamma.$$

$$\text{When } n = \frac{\beta + \gamma}{2\gamma}.$$

III. *Supersaturation of Salt Solutions.*[1]

In these papers experiments are described which lead to the conclusion that the only truly supersaturated solutions are those which result from the fact that, when a hot solution is cooled, a finite time is required for the excess of salt to crystallize out—what is usually

[1] Published (1) *Phil. Mag.*, June, 1885; (2) *Phil. Mag.*, September, 1885.

termed supersaturation is not really so at all. Thus a distinctly supersaturated solution of sodium sulphate readily dissolves a quantity of the dehydrated salt when brought in contact with it without access of air. This shows that the solution is not even saturated, much less supersaturated; still this may be explained by the supposition that the constitution of a supersaturated solution is not the same as an ordinary one, inasmuch as heat is necessary for its preparation; the effect of heat being to decompose the decahydrate, no union of water and salt taking place in cooling. In the second paper it is shown that this is entirely a mistake. Supersaturated solutions are readily prepared in the *cold* by simply enclosing the dehydrated salt in a bulb, placing this in a bottle with the proper quantity of water, and, after closing, heating the bottle to 100° for a few minutes. When the whole is *cold*, the bottle is shaken, the bulb broken, and the salt readily dissolves. If excess of salt be used, the solution has the same percentage composition as one prepared by heating the decahydrate, and allowing it to cool with the excess of salt to the same temperature, air being excluded. It is further found that when the dehydrated salt is brought in contact with the water, as above described, no caking together is observable, the powdery condition being retained till solution is complete. Thus there is no hydration previous to solution, as is indeed shown by the possibility of preparing supersaturated solutions in this way, for were the smallest trace of the decahydrate produced such a solution, could not be formed. During the act of solution, however, considerable heat is evolved, which, as shown above, cannot be due to hydration, but may possibly result from the enormous contraction, about 40 per cent., undergone by the salt.

Finally, density determinations of solutions of Na_2SO_4 and $Na_2S_2O_3$, of various strengths, show that in passing the ordinary saturation point there is nothing to indicate any change in the constitution of the solution. The molecular volume steadily increases from the most dilute solution up to the most concentrated supersaturated solution examined, exactly as it does with an ordinary solution which is not capable of supersaturation.

From these and other experiments it follows that a so-called supersaturated solution is simply a saturated or non-saturated solution of the anhydrous salt; that any solution of a hydrated salt contains no hydrate of that salt, but that it is at the moment of crystallization that combination of the water and salt takes place.

IV. *Vapour Pressures of Salt Solutions.* 1. *Boiling Points of Saturated Solutions.*[1]

The method of experiment was to measure the pressure under which a saturated solution of the salt boiled at a definite temperature. The experiments included determinations at 65°, 75°, 85°, and 95° for $NaNO_3$, KNO_3, Na_2CO_3, K_2CO_3, $MnSO_4$, $FeSO_4$, and the results are expressed in terms of degrees of rise of boiling point. This is found to be a quantity increasing with the temperature when the solubility increases; on the other hand, it decreases when the solubility diminishes with rise of temperature.

It is preferable, however, to express the effect of salt on the

[1] Published *Phil. Mag.*, October 1885.

vapour pressure of water by the value $\frac{1-p^1}{pn}$; where p = pressure of vapour of pure water, p^1 = pressure of water vapour from salt solution containing n molecules per 100 H_2O, and this, as was to be expected, is in all cases a diminishing quantity with rise of temperature—showing that, in a constantly saturated solution, a salt exercises a less restraining effect on the water the higher the temperature.

2. *Vapour Pressure of Water from Non-saturated Salt Solutions.*

The experiments on this subject are not yet complete, but are sufficiently advanced to justify certain conclusions regarding the behaviour of salts under varying conditions of temperature and concentration.

The method employed was the same as that in the previous section, with this difference, that a dilute, not a saturated, solution of the salt was employed, and successive portions of water were distilled off and weighed. In this way the concentration at different pressures and at a definite temperature was readily determined.

Four salts have, as yet, been examined, NaCl, KCl, $NaNO_3$, and KNO_3. The temperature chosen was 70°, though some experiments were made at 90°.

Two of the above salts have been examined in solutions of constant strength at temperatures of 70°, 75°, 80°, 85°, and 90°.

The general results are as follows:—

(α) When temperature is constant and n varying, then $\frac{p-p}{n}$ increases with increase of n in the case of NaCl; is constant, or nearly so, with KCl, and diminishes more or less rapidly with $NaNO_3$ and KNO_3. These results are fully confirmed by Tammann's results, obtained by the Barometric method (Wiedem. *Ann.* 24), a close agreement being found between the two sets of figures.

(β) When the concentration is constant but temperature varying, then the value of $\frac{p-p^1}{pn}$ or $1-\frac{p^1}{pn}$ is a diminishing one with NaCl and a slowly increasing one in the case of the other three salts. This also is confirmed by Tammann's results, and general agreement is to be found with the experiments of Legrand (1835), conducted in an entirely different way.

It is believed that there is an intimate connection between this behaviour of the salts and their solubility, but the discussion of this question is postponed till the results are more numerous and complete.

V. *Expansion of Salt Solutions.*

The dilatation of solutions containing definite numbers of molecules, 1, 3, 5, or 2, 4, 6, &c., of NaCl, KCl, $NaNO_3$, and KNO_3, have been determined by means of specially constructed dilatometers, and a special constant temperature bath, by means of which a tube 700mm. long can be kept for any length of time at a definite temperature, the temperature of the one end differing from that of the other not more than 0°·1. Thus all necessity for correction of the results for the exposed portion of the stem of the dilatometer is avoided.

As in the previous section, the experiments are not yet complete, but have fully established the following conclusions:—

(α) The expansion of a salt solution is the more uniform the more concentrated it is. The curves representing the expansion approach more nearly straight lines as n increases.

(β) At low temperatures salt solutions expand more than water, at higher ones less; there is thus a point at which the coefficient of expansion is the same as that of water. This temperature is little, if at all, affected by the concentration. They are as follows:—

NaCl . .	55°– 60°
KCl . .	50°– 55°
$NaNO_3$ . .	80°–100°
KNO_3 . .	75°– 80°

(γ) The volumes at different temperatures may be satisfactorily expressed by interpolation formulæ of the form

$$V=100{,}000+t'\alpha+t'^2\beta\,;$$

Where $t'=t°-20°$, and α and β constants depending on the salt and the value of n. In 126 determinations only two differed from the calculated value by more than $\frac{\pm 5}{100{,}000}$, the mean error being less than $\frac{\pm 2}{100{,}000}$. The constants α and β are thus related; as n increases α increases, but β decreases; the expansion approximating more and more to $100{,}000+\alpha\, t'$.

The results confirm in most points those of Kremers, and it is hoped when the experiments are complete that it will be possible to establish the connection between the vapour pressures and the molecular volumes, as has already been attempted by Tammann in an incomplete form.

Report of the Committee, consisting of Professor Sir H. E. ROSCOE, Mr. J. N. LOCKYER, Professors DEWAR, WOLCOTT GIBBS, LIVEING, SCHUSTER, *and* W. N. HARTLEY, Captain ABNEY, *and* Dr. MARSHALL WATTS (*Secretary*), *appointed for the purpose of preparing a new series of Wave-length Tables of the Spectra of the Elements and Compounds.*

THE present Report contains the completion of the tables of the spectra of the elements, and a portion of those of the spectra of compounds. The measurements are given in ten-millionths of a millimetre (or tenth-metres), and are based upon the measurements of the Fraunhofer lines by Ångström for the whole visible rays, and the extension of the same series of measurements into the ultra-violet portion of the spectrum made by Cornu and other observers. It will be well to repeat here the fundamental values of wave-length of the chief solar lines. The small corrections indicated at page 29 of Ångström's Memoir, 'Le Spectre Normal du Soleil,' have been applied to his numbers—but they are uncorrected for the dispersion of air. Hence the numbers in the tables represent wave-lengths in air of 760mm pressure at Upsala, and 16° C. temperature. The numbers taken from Thalén's 'Détermination des Longueurs d'Onde des Raies Métalliques' in the same way have had applied to them the necessary small corrections to bring them into harmony with the numbers finally adopted by Ångström as 'Valeurs définitives' (pp. 25 and 31–32).

FRAUNHOFER LINES

A		7604·0	
B		6867·0	
C	(H)	6562·1	
D	(Na)	5892·12 { 5895·13 / 5889·12	
E	(Ca & Fe)	5269·13	
b_1	(Mg)	5183·10	
b_2	(Mg)	5172·16	
b_3	(Ni & Fe)	5168·48	
b_4	(Mg & Fe)	5166·88	
F	(H)	4860·72	
G	(Fe)	4307·25	
H	(Ca)	3968·1	
K	(Ca)	3933·0	
L	(Fe)	3819·8	
M	(Fe)	3727·0	
N	(Fe)	3580·5	
O	(Fe, double)	3439·8	
P	(Fe & Ti)	3359·2	
Q	(Fe)	3284·9	
R	(Fe & Ca)	3179·0	
r	(Fe, double)	3144·3	
S_1	(Ni, double)	3100·6	} 3100·0
S_2	(Fe, triple)	3099·5	
s	(Fe)	3046·4	
T	(Fe, double)	3019·7	
t	(Fe)	2994·3	
U	(Fe)	2947·8	

The following symbols are employed in the tables to indicate the character of the lines :

s denotes that the line is sharply defined.
n denotes that the line is ill-defined or nebulous.
b denotes a band, the position of the brightest part being given.
b^r denotes a band sharply defined on the least refracted side, and fading away towards the blue.
b^v denotes a band sharply defined on its more refracted side, and fading away towards the red.

The width of a broad band is sometimes indicated by a *suffix*, giving the width in ninth-metres; thus, 4997 b^r_5 means that the bright edge of the band is the 4997, and that it fades away above 4947 ; whereas 6532 b_4 means that the band extends from 6552 to 6512, its brightest point being at 6532.

c denotes that the line is continuous.
d denotes that the line is discontinuous, or a 'short' line.
r denotes that the line is frequently 'reversed.'
A number within parentheses, thus : (3091·9), means that while a line in this position has been observed, no new measurements of wave-length was made —the wave-length being quoted from another observer.

The intensities of the lines are expressed upon an ascending scale from 1 to 10 ; 1 being the feeblest and 10 the brightest.

WAVE-LENGTH TABLES OF THE SPECTRA OF THE ELEMENTS.

Sulphur.

I. Band Spectrum	II. Line Spectrum				Intensity and Character	
Salet	Ångström	Hasselberg	Plücker and Hittorf	Salet	I.	II.
			6579			2
			6454			2
			6421			4
			6404	6400		8
			6390	6390		6
			6321	6325		8
			6309	6310		8
			6290	6290		10
6145			6152		1b^v	2
6090			6111		1b^v	2
6030					1b^v	
			6009			4
5970			?		2b^v	
5900					2b^v	
			5866			4
5845					2b^v	
			5810			4
5780			5780		2b^v	4
5715					2b^v	
	5671		5667	5670		6
		5659·7	5657	5660		8
			5650	5655		8
5645	5645	5639·3	5641	α 5647	3b^v	10
			5618			4
	5613	5603·8	5609	5610		10
5595					3b^v	
			5584			4
		5561·3	5568	5570		8
			5558			4
5535			5532		3b^v	2
		5516·9	5522			4
		5507·3	5508	5510		8
5480					3b^v	
	5474	5470·5	5473	5477		8
	5451	5451·0	5452	β *5455		10
	5432	5438·1	5438	5432		8
5425		5429·7	5425		3b^v	6
		5418·4				
		5386·6				
5365					5b^v	
	5345	5341·7	5338	γ 5350		10
5310	5322	5319·2	5304	5320	2b^v	10
			5269			2
			5231			4
		5217·8	5218			2
5250	5207		5207	5220	8b^v	8
				5217 δ		8
5190	5191	5214·4	5199	5205	8b^v	10
			5191			2
		5200·1	5182			10
				5160		
5143		5142·5	5143		2b^v	6
			5141			2
			5140			2

SULPHUR—*continued.*

I. Band Spectrum	II. Line Spectrum				Intensity and Character	
Salet	Ångström	Hasselberg	Plücker and Hittorf	Salet	I.	II.
			5124			4
			5110			2
5088		5102·9	5096	5103	8bv	8
		5078.3	5068			2
5040		5044·9	5044		8bv	4
			5036			2
	5027	5032·5	5030	5030		10
			5024	5024		10
	5013	5012·7	5013	5013		8
			5004	ε 5008		8
			5003			2
4990	4994	4993·9	5000	5000	6bv	4
			4990	4990		6
4945		4941·5	4942		6bv	4
	4926	4925	4924	ζ4925		8
		4918·5	4922			6
		4901·9	4902			6
4890		4884·5	4884		2b	6
4840					8bv	
			4825	4825		6
		4815·6	4813	η4810		8
		4808·5	4804			4
4795		4792·8	4791		7bv	4
		4778·5	4777			2
		4762·8	4768			2
		4752·8	4762			2
4755					2bv	
			4734			2
			4723			2
		4714·9	4718	θ4715		8
4705					5bv	
			4692	4690		b
			4671	4670		b
4655			4657	4655	6bv	b
			4630	4630		b
4615			4610	4610	8bv	b
			4593	4590		b
			4580	4580		b
			4561	4560		b
		4551·5	4552	4556		10
4540					2br	
		4524·7	4523	4525		10
		4485·1	4485	μ 4485		10
4470					8bv	
		4464·0	4466	4467		10
4450					2b	
			4432	4435		b
			4422	4425		b
4367			4386	4390	3b	b
			4358			4
			4350			4
			4343			4
			4336			4
			4329			4
4320					2b	
			4315	4315		b

SULPHUR—*continued.*

I. Band Spectrum	II. Line Spectrum		Intensity and Character		I. Band Spectrum	II. Line Spectrum		Intensity and Character	
Salet	Plücker & Hittorf	Salet	I.	II.	Salet	Plücker & Hittorf	Salet	I.	II.
	4297	4295		8		4196	4192		b
	4284	4282		8	4187			2b	
	4279			4		4181	4180		6
	4272	π 4269		8		4168	ρ 4162		8
	4259			4		4158	4155		6
	4255	4250		8		4140			6
	4241			b	4070			2b	2½
	4229			b					

* Double.

TANTALUM.

Arc Spectrum	Intensity and Character	Arc Spectrum	Intensity and Character	Arc Spectrum	Intensity and Character
Lockyer		Lockyer		Lockyer	
3998·6		3975·5		3942·7	
3995·7		3973·0		3940·3	
3995·0		3971·6		3936·3	
3991·0		3971·2		3914·0	
3987·4		3964·5		3911·0	
3979·7		3963·3		3906·9	

TELLURIUM.

I. Band Spectrum	II. Line Spectrum			Intensity and Character	
Salet	Salet	Huggins	Thalén	I.	
		6645			4
	(6437)	6431	6437·2		10s
		6366			1s
		6347			1n
		6290			2s
6250		6243		5b	3n
		6228			3s
6150				5b	
6050	(6046)	6042	6046·2	5b	6sd
	(6012)	6010	6012·7		6sd
		5995			1n
	(5973)	5970	5973·2		10sc
5940	(5935)	5934	5935·2	5b	8sc
	(5856)	5854	5856·6		4sd
5855	(5852)	5849	5852·1	7b	4sd
	(5825)		5825·1		4nd
	(5805)		5805·6		4nd
			5781·1		6sd
	(5755)	5756	5755·1		10sc
		5740	5741·1		2sd
5735				8b	
	(5707)	5708	5706·6		10sc
5685				8b	
	(5647)	5646	5647·1		10sc
		5618	5616·1		4sd
	(5574)	5575	5574·1		8sc
5560				4b	
	(5488)	5486	5488·1		6sd

TELLURIUM—*continued.*

I. Band Spectrum	II. Line Spectrum			Intensity and Character	
Salet	Salet	Huggins	Thalén	I.	II.
5470	(5477)	5476	5477·6	4b	6sd
	(5447)	5447	5447·6		8sc
5410				4b	4sd
		5409	5408·6		
	(5366)	5366	5366·1		6sc
5340				4b	
	(5310)	5309	5310·1		6sd
		5298	5299·1		2sd
5278				4b	
5220	(5217)	5222	5217·2	4b	8nc
			5172·2		2sd
5156	(5152)		5152·2	4b	6sd
		5134	5133·2		2nd
	(5104)		5104·1		6sd
5070				4b	
		5038	5035·1		4sd
5015				4b	
4970				4b	
4920				4b	
			4895·1		2nd
4870	(4866)	4866	4866·6	4b	4nd
		4832	4832·1		2nd
4820				4b	
	Hartley and Adeney	4785	4785·1		2nd
4767				8b	
4725				8b	
	4707·5	4709			4sd
	4693·0				4sd
4670				8b	
		4664			1n
		4652			1n
4600	4602·0	4602	4603·6	6b	2sd
		4599			1n
4560				6b	
		4544			b
4510				6b	
	4487·0				2sd
	4480·0	4479			2sd
4470				4b	
	4436·0				2sd
4400	4400·0			4b	2sd
	4378·0				2sd
	4364·5				2sd
4350	4353·0	4352		2b	2sd
4330	4324·6			2b	4sd
	4301·5	4302			6sd
4280	4292·7			2b	4sd
	4287·3				4sd
	4274·4				6sd
	4259·8	4259			6sd
4250				2b	
	4221·1				6sd
4200				2b	
	4180·7				2sd
	4170·3				4sd
4150				2b	
	4119·7				4sd
	4072·7				2sd
	4061·3	4063			6sd

TELLURIUM—*continued.*

Line Spectrum — Hartley and Adeney	Intensity and Character	Line Spectrum — Hartley and Adeney	Intensity and Character	Line Spectrum — Hartley and Adeney	Intensity and Character
4054·2	6sd	3322·7	4sd	2923·4	4sd
4048·3	4sd	3315·8	4sd	2918·9	2sd
4006·0	8sd	3307·1	8sc	2905·9	2sd
3983·8	6sd	3289·6	2sc	2901·9	4sd
3968·6	6sd	3280·0	10sc	2894·3	8nd
3948·0	6sd	3273·4	10sc	2893·3	6sd
3932·5	2sd	3267·4	2sd	2877·4	2sd
3908·7	2nd	3264·6	2sd	2873·6	2sd
3841·3	8sd	3256·3	8sd	2867·7	8nd
3803·0	4sd	3250·8	4sd	2859·9	6sd
3796·9	2sd	3246·8	10sc	2857·0	8nd
3789·0	4sd	3242·1	4sd	2844·9	6sd
3776·0	4sd	3234·2	4sd	2840·0	6sd
3771·0	4sd	3229·4	2sd	2836·9	2sd
3765·0	4sd	3221·8	4sd	2834·4	2sd
3759·0	4sd	3217·6	4sd	2823·2	6sc
3754·0	4sd	3213·3	4sd	2815·3	2sd
3735·5	8sd	3210·4	2sd	2813·0	2sd
3726·2	8sd	3192·2	4sc	2799·1	4sd
3716·0	4sd	3188·1	4sc	2795·5	4sd
3698·7	4sd	3183·7	2sd	2791·9	8nd
3683·3	4sd	3174·4	4sc	2768·6	6sc
3676·7	4sd	3168·5	4sd	2766·5	6sd
3670·4	4sd	3158·4	2sd	2766·0	4sc
3656·4	4sd	3154·1	4sd	2756·0	2sc
3649·2	6sd	3145·7	4sd	2751·5	2nd
3644·3	6sd	3131·7	2sd	2745·0	4sd
3636·3	4sd	3124·7	2sd	2743·0	4sd
3626·7	4sd	3119·5	4nd	2739·5	4sd
3617·0	6sd	3107·5	6sd	2738·0	4sd
3611·0	4sd	3098·7	4sd	2723·2	2nd
3601·7	4sd	3095·5	4sd	2720·7	2sd
3599·6	4sd	3088·0	4sd	2718·0	2sd
3594·5	4sd	3072·7	6sd	2713·0	2sd
3589·4	4sd	3063·2	2sd	2710·2	8nd
3551·6	8sd	3052·8	2sd	2702·3	2sd
3541·8	4sd	3046·0	8nc	2700·3	2sd
3533·1	4sd	3022·1	2sc	2696·6	6nd
3520·3	8sd	3016·6	8sd	2694·1	6nd
3510·8	2sd	3012·1	4sd	2690·2	2sd
3496·3	8sd	3004·1	4sd	2688·2	2sd
3483·7	2sd	2996·4	4sd	2683·2	2nd
3480·8	4sd	2988·8	4sd	2679·8	2nd
3474·4	2sd	2976·2	4sd	2674·6	2sc
3465·5	4sd	2975·5	4sd	2666·0	4sd
3456·0	8sd	2973·1	2sd	2659·4	2b^{v}d
3450·4	2sd	2966·1	8sd	2657·1	4nd
3441·2	8sd	2960·3	2sc	2648·7	2nd
3422·2	4sd	2956·3	2sd	2647·0	2nd
3415·3	4sd	2950·6	2sd	2642·3	2nd
3407·5	8sd	2948·8	2sd	2637·0	2sd
3382·4	10sc	2945·3	2sd	2634·7	6nd
3374·1	4sd	2940·8	8sd	2630·5	2nd
3362·4	8sd	2937·7	4sd	2627·8	4sd
3352·1	6sd	2932·5	4sd	2624·3	4sd
3329·0	6sd	2928·1	2sd	2621·4	4sd

TELLURIUM—*continued.*

Line Spectrum — Hartley and Adeney	Intensity and Character	Line Spectrum — Hartley and Adeney	Intensity and Character	Line Spectrum — Hartley and Adeney	Intensity and Character
2617·4	2sc	2420·3	2nd	2231·3	2nc
2613·7	4sd	2418·5	2nd	2230·3	2nc
2611·3	4sd	2413·3	8sc	2229·0	2nc
2604·4	2nd	2411·4	6sc	2226·8	2nd
2599·4	2sd	2403·7	6nd	2223·2	2nd
2598·1	2sd	2400·0	6sc	2219·3	6b^{r}c
2594·0	2sd	2392·8	4nd	2216·0	2nc
2590·1	2nd	2390·7	4nd	2211·2	6nd
2585·0	2nd	2386·3	10nc	2209·5	6nd
2580·1	2nd	2383·8	10nc	2202·8	2nd
2578·0	2nd	2377·0	2nd	2200·1	2nd
2574·8	4sd	2375·3	2nd	2196·5	2nd
2572·4	4nd	2370·3	8sc	2192·2	6nc
2567·8	2nd	2364·7	4nd	2189·7	6nd
2564·1	2nd	2362·8	4nd	2186·9	2nd
2558·7	2nd	2359·8	4nd	2182·0	2nd
2549·7	2nd	2358·6	6sd	2179·2	6nc
2543·7	6sd	2357·0	4nd	2175·3	2nd
2536·8	2nd	2351·7	2nd	2167·2	2nd
2533·8	2sd	2344·3	2nd	2165·7	2nd
2529·4	8sc	2340·3	2nd	2159·7	2nd
2528·3	2nc	2336·8	2nd	2149·7	2nd
2525·6	2sd	2332·0	8sd	2147·8	2nc
2505·2	6sd	2325·5	8sd	2146·7	2nd
2502·7	2sd	2321·0	8sd	2142·7	2nd
2498·6	6nd	2317·8	8sd	2136·5	2nd
2491·3	2sc	2310·1	2nd	2135·0	2nd
2490·8	2nd	2303·7	2nd	2125·5	2nd
2488·7	2sd	2301·1	2nd	2122·5	2nd
2485·3	2nd	2297·5	2nd	2119·0	2nd
2480·9	2sd	2295·0	6nc	2116·3	2nd
2479·6	2nd	2291·8	2nd	2113·3	2nd
2476·7	2nd	2288·6	2nd	2110·5	2nd
2473·2	6sd	2280·6	6nd	2108·4	2nd
2469·0	2nd	2277·2	6nd	2103·6	2nd
2462·0	4nd	2285·7	6nd	2100·2	2nd
2460·2	4nd	2266·2	6nc	2078·5	2nd
2452·8	2nd	2264·2	2nd	2050·8	2nd
2447·8	6sd	2260·4	6nc	2039·2	2nd
2444·3	2nd	2256·6	6nc	2032·7	2nd
2441·7	2sc	2250·0	6nd		
2438·0	8sc	2248·0	6sc		
2432·0	2nc	2247·3	6nc		
2429·7	2nd	2243·3	6b^{r}c		
2428·2	2sc	2240·7	2nd		
2426·7	2nd				
2425·0	4nd				

Terbium.

Spark Spectrum — Roscoe and Schuster	Intensity and Character	Spark Spectrum — Roscoe and Schuster	Intensity and Character	Spark Spectrum — Roscoe and Schuster	Intensity and Character
5371·4	6	5091·9	5	4603·5	2
5369·4	4	5073·9	4	4600·3	4
5368·3	4	5070·7	6	4597·3	2
5367·2	6d	5069·2	6	4596·3	2
5360·3	4	5066·5	3	4594·3	3
5352·1	5	5060·6	2	4593·0	3
5349·6	7	5057·2	4	4590·8	2
5347·7	5	5052·3	8	4589·0	2
5342·3	6	5050·9	2	4584·1	4
5340·0	5	5030·4	6	4581·7	4
5331·4 ?	2n	5027·9	6	4580·5	2
5320·5	7	5014·6	6	4576·9	5
5318·7	7	4960·9	6	4565·7	5
5306·4	7	4956·6	5	4560·3	2
5301·6	7	4951·7	5	4557·6	2
5300·6	7	4947·6	6	4553·5	3
5292·3	3	4937·1	4	4552·4	3
5281·6	6	4935·5	4	4543·6	5
5280·4	6	4933·1	2	4541·3	4
5271·9	3	4911·9	2	4539·3	5
5270·6	7	4909·0	3	4537·2	6
5268·8	6	4893·2	2	4523·6	5
5264·5 ?	2	4864·2	2	4522·7	4
5261·4 ?	6	4847·0	5	4521·9	2
5254·8	5	4843·7	2	4519·2	5
5251·1	7	4841·2	2	4511·5	4
5250·1	5	4821·1	3	4498·7	4
5248·6	4	4815·0	7	4497·6	3
5236·7	3	4799·8	4	4496·9	4
5233·3	4	4790·2	4	4483·9	2
5232·0	3	4781·9	2	4482·8	3
5218·7	5	4776·7	3	4480·6	3
5197·1	6	4773·6	2	4475·9	2
5195·1	3	4766·1	3	†4473·4	2
5192·0	6	4757·6	2	4472·2	4
5190·3	6	4754·5	2	4470·9	3
5185·8	6	4744·8	6	4466·9	7
5182·8	5	4743·0	3	4466·1	2
5175·4	7	4725·4	2	4462·6	2
5174·6	7	4720·0	2	4458·3	5
5172·3	7	4717·0	2	4454·3	6
5165·6	3	4715·0	2	4452·6	6
5155·2	5	4712·0	4	4449·6	2
5154·4	4	4703·5	6	4444·0	4
5140·5	2	4700·2	6	4441·8	2
5129·8	4	4686·5	4	4437·8	3
5124·9	2n	4676·1	5	4435·6	4
5121·5	3	*4673·6	5	4435·1	4b
5116·5	4	4668·6	6	4433·7	7
5111·8	1	4654·5	3	4430·1	2
5108 5	4	4646·4	2	4427·3	2
5104·2	3	4641·6	5	4423·8	8
5102·9	5	4638·0	3	4420·6	3
5100·1	7	4635·9	2	4420·3	3
5097·8	4	4614·9	5	4418·7	3

TERBIUM—*continued.*

Spark Spectrum Roscoe and Schuster	Intensity and Character	Spark Spectrum Roscoe and Schuster	Intensity and Character	Spark Spectrum Roscoe and Schuster	Intensity and Character
4414·3	4	4373·4	3	4333·4	3
4408·9	3	4369·2	5	4329·8	2
4407·7	3	4361·4	4	4328·4	4
4406·3	4	4360·4	5	4326·1	3
4402·7	6	4351·6	6	4325·0	4
4401·4	6	4350·2	6	4318·4	5
4390·4	5	4347·1	6	†4315·3	2
4387·1	2	4346·0	4	†4313·1	2
4382·4	2	4341·7	8	4308·7	5
4380·1	2	4335·5	6		

* Less refrangible than the Yttrium line 4673·8. † Double.

THALLIUM.

I. Flame Spectrum	II. Spark Spectrum		III. Arc Spectrum	Intensity and Character		
Lecoq de Boisbaudran	Huggins	Thalén	Liveing and Dewar	I.	II.	III.
	6547				4s	
	6240				1n	
	6002				2s	
	5949	5947·7			6nc	
	5824				2s	
	5771				1n	
5680				3n		
		5608·1			2sd	
	5487	5490·1			2sd	
		5412·6			4nd	
		5360·1			4sd	
*5349	5347	5349·6	(5349·6)	10sc	10nc	r
	5153	5152·7			8nc	
		5085·1			4sd	
	5078	5078·6			6nd	
	5054	5053·1			6sd	
	4980	4981·6			6nd	
		4945·6			4sd	
	4893	4892·1			4sd	
	4767				2n	
	4737	4735·6			6nd	
	4112					
			3775·6			
			3528·3			
			3517·8			
			3228·1			
			2943·9			

THALLIUM—*continued.*

Arc Spectrum	Intensity and Character	Arc Spectrum	Intensity and Character
Liveing and Dewar		Liveing and Dewar	
2921·3	10	2699·7	n
2917·8	10	2665·0	n
2895·2		2652·3	
2825·8		2609·4	r
2826·9		2608·6	8r
2714·6	n	2552·0	r
2710·4	r	2517·0	n
2708·8	8nr		

* 5348·0 Müller; 4345·1 Ketteler; 5352 Bernard; 5348 Rühlmann; 5348·8 Mascart.

THORIUM.

Spark Spectrum	Intensity and Character	Spark Spectrum	Intensity and Character
Thalén		Thalén	
5698·6	2sd	4863·6	6sd
5640·1	2sd	4392·5	10nc
5537·1	6sd	4381·5	10nc
5446·1	6sd	4281·0	10sc
5374·6	6sd	4277·5	8sc
4919·1	6sd	4272·5	6sc

Lockyer has observed the following lines in the arc spectrum of Thorium between wave-lengths 3900 and 4000:—3999·6, 3995·3, 3993·7, 3991·0, 3989·8, 3987·3, 3986·4, 3980·4, 3979·4, 3975·3, 3972·4, 3971·2, 3966·6, 3959·2, 3958·5, 3955·0, 3953·8, 3945·1, 3944·4, 3940·3, 3937·8, 3937·2, 3936·2, 3934·7, 3931·9, 3931·1, 3928·5, 3924·4, 3918·3, 3900·5.

THULIUM.

Spark Spectrum	Intensity and Character	Spark Spectrum	Intensity and Character
Thalén		Thalén	
5961·5	1	4481·0	2
5896·0	5	4386·5	3
5675·0	3	4359·5	3
5305·7	5	4241·5	2
5033·5	4	4204·0	2
4733·0	1	4187·5	2
4615·0	2	4106·5	1
4522·0	3	4093·0	1

Tin.

I. Spark Spectrum				II. Arc Spectrum	Intensity and Character	
Huggins	Thalén	Kirchhoff	Hartley and Adeney	Liveing and Dewar	I.	II.
6840		6837·4			3n	
6769						
6573						
*6447	†6452·3$^{(3)}$	6452·8			10nc	
*5798	†5798·1$^{(3)}$	5798·4			10nc	
*5630	†5630·1$^{(4)}$					
*5587	†5588·6$^{(3)}$	5587·8			10nc	
*5564	†5562·6$^{(3)}$	5561·6			10nc	
5366	†5368·6$^{(1)}$					
5347	†5347·6$^{(1)}$					
*5333	†5332·1$^{(3)}$					
5328						
5287	†5289·6$^{(1)}$					
5224	†5224·2$^{(2)}$					
5098	†5100·6$^{(2)}$	5100·0			6sc	
	†5021·1$^{(1)}$					
	†4923·1$^{(1)}$					
4858	†4858·1$^{(2)}$	4858·1			6sc	
4584	†4584·6$^{(1)}$	4584·7	4584·3		8sc	
*4523	†4524·1$^{(4)}$	‖4523·9	4524·0		‡10nc	
			4324·6		2sd	
			4215·3		2sd	
			4057·0		2sd	
			3961·8		6sd	
			3947·0		2sd	
			3906·6		8sd	
			3859·0		8sd	
			3800·3		8sc	
			3783·4		8sd	
			3779·0		8sd	
			3763·9		6sd	
			3745·1		10sd	
			3734·4		8sd	
			3727·0		6sd	
			3707·6		8sd	
			3686·7		2sd	
			3667·6		2sd	
			3655·5		2sd	
			3623·9		4sd	
			3616·9		4sd	
			3609·3		8sd	
			3598·3		10sd	
			3574·0		8sd	
			3549·7		6sd	
			3539·3		4sd	
			3514·8		4sd	
			3487·3		4sd	
			3471·1		2sd	
			3412·7		8sd	
			3390·4		2sd	
			3351·8		10nd	
			3330·0		10sc	
				3326·0		
			3314·6		2sd	

TIN—*continued.*

I. Spark Spectrum	II. Arc Spectrum	Intensity and Character		I. Spark Spectrum	II. Arc Spectrum	Intensity and Character	
Hartley and Adeney	Liveing and Dewar	I.	II.	Hartley and Adeney	Liveing and Dewar	I.	II.
3282·9		10nd		2617·9		8sd	
3261·6	§3260·0	10sc		2613·8		4sd	
3245·0		2sd		2611·0		4sd	
3219·6		4sd		2606·3		4sd	
3218·0		4sd		2598·5		4sd	
3174·3	3175·0	10sc		2593·6	2593·5	6sc	
	3141·7			2591·7		6sc	
3140·6		2sd		2570·5	2571·0	8sc	
3122·3		2sd		2563·2		4nd	
3131·0		4sd		2557·7	2557·5	4sc	
3095·2		4sd		2545·6	2546·1	8sc	
3070·6		8sd		2530·8	2530·7	4sd	
3046·5		2sd		2523·4	2523·5	4sd	
3033·1	3033·0	10sc		2514·0		4sd	
3007·9	3008·5	10sc		2506·0		4sd	
	2986·4			2499·3		4sd	
	2913·1			2495·0	2495·5	8sc	
2911·9		2sc			2493·5		
2895·0		8sd		2488·0		8nd	
2886·9		8sd		2482·9	2483·1	8sc	
2877·4		2sd		2455·5		2sd	
2874·7		4sd		2449·4		6nd	
2862·1	2862·8	10sc		2445·2		2sc	
2849·3		8sc		2436·4		8sd	
2847·6		8sc		2433·3		4sd	
	2839·5			2429·3	2429·5	10sc	
2838·9		10sc		2421·8	2421·5	10sc	
	2813·5			2408·0	2407·9	2sd	
2812·5	2812·5	8sc		2395·8		4sd	
2811·5		4sd		2393·7		4sd	
2787·3	2787·5	4sd		2382·3	2392·5	4sd	
2784·0	2784·7	6sc		2381·7		2sd	
	2779·5			2368·3		8sd	
2778·0		8sc			2364·7		
2778·8		8sc			2357·7		
2765·0		4sc		2355·0	2354·5	10sc	
2754·0		4sd		2335·3	2334·3	8sd	
2751·8		4sd		2317·9	2317·0	8nc	
2749·0		4sd		2288·1		6sd	
2746·0		4sd			2286·9		
2738·4		4sd			2282·5		
2733·0		4sc			2275·4		
2705·8		10sc		2270·0		8nd	
2664·9		8sd		2268·6		4sd	
2660·2	2660·7	8sc		2267·1		2sd	
2657·9		10nd			2251·0		10r
2645·4		8sc		2247·0		8sd	
2643·2		10nd			2245·8		10
	2636·5			2233·2		4sd	
2631·5		10nd			2231·3		

TIN—*continued.*

I. Spark Spectrum	II. Arc Spectrum	Intensity and Character	I. Spark Spectrum	II. Arc Spectrum	Intensity and Character
Hartley and Adeney	Liveing and Dewar	I.	Hartley and Adeney	Liveing and Dewar	I.
2229·6		8sd	2151·2		2sd
2221·5		8sd	2119·2		4sd
2215·2		2sd	2113·6		4sd
2210·1	2210·7	6sd	2079·3		4sd
2199·2	2198·7	2sd	2066·1		4sd
2195·0	2194·1	2sd			

* Observed also by Lecoq de Boisbaudran in the Spark Spectrum of Stannous Chloride solution.
† Observed also by Lockyer; the 'indices' attached to these numbers denote the relative 'lengths' of the lines. ‡ 2sd in Hartley and Adeney's photograph. ‖ 4523·3, Mascart. § 3259·9, Cornu.

TITANIUM.

I. Spark Spectrum		II. Arc Spectrum		Intensity and Character	
Cornu	Thalén	Ångström	Liveing and Dewar	I.	II.
	6556·0			4sd	
	6543·1			2sd	
	6260·4	6260·4	(6260·4)	8sc	r
	6257·6		*(6257·6)	10nc	r
	6221·1			6sd	
		6218·5			
	6214·3	6214·3		6sd	
		6127·0			
	6125·4			8sd	
	6097·6	6097·6		6sd	
	6090·6	6090·6		8sc	
	6083·4	6083·4		6sd	
	6064·7	6064·7		8sc	
5998·0	5998·9	5998·9		8sd	
	5978·2	5978·2		10sc	
5976·9					
	5965·5	5965·5		10sc	
5964·4					
5951·5	5952·0	5952·0		10sc	
5940·3					
5920·7	5921·7			6sd	
5918·2	5919·0			6sd	
5898·1	5899·1	5899·1		10sc	
	5865·4	5865·4		10sc	
	5738·1			6sd	
	5714·1	5714·1		4sd	
	5701·6			2nd	
	5688·6	5688·6		8sd	
	5679·1	5679·1		6sd	
	5674·4	5674·4		10sc	
	5661·6	5661·6		10sc	
	5647·1			4sd	
	5643·1	5643·1		10sc	
	5629·1			2nd	

TITANIUM—*continued.*

I. Spark Spectrum	II. Arc Spectrum		Intensity and Character		I. Spark Spectrum	II. Arc Spectrum		Intensity and Character	
Thalén	Ångström	Liveing and Dewar	I.	II.	Thalén	Ångström	Liveing and Dewar	I.	II.
5597·3			2nd		5128·7	5128·7	(5128·7)	10sc	r
5564·7	5564·7		6sc		5126·7			4sd	
5513·5	5513·4		10sc		5120·0	5120·0		10sc	
5511·9	5511·9		10sc		5113·1			8sd	
5502·9	5502·9		8sc		5108·7			4sd	
5489·0	5489·0		8sc		5102·5			4sd	
5486·9	5486·9		6sd		5086·6			8nd	
5480·3	5480·3		8sc		5076·6			4nd	
5476·6			6sd		5071·9			4nd	
5473·4	5473·4		6sd		5065·6			4sd	
5470·6	5470·6		4sd		5064·5	5064·2	(5064·5)	10sc	r
5448·1	5448·1		6sd		5061·4			6sd	
5445·9	5445·9		4sd		5052·4			6sd	
5428·7	5428·7		8sc		5043·5			6sd	
5425·1	5425·1		6sd		5039·3	5039·3	(5039·3)	8sd	r
5418·0	5418.0		4sd		5038·1	5038·1	(5038·1)	8sd	r
5408·7	5408·7		8sc		5035·7	*5035·7	(5035·7)	10sc	r
5403·1	5403·1		6sc		5024·9			6sd	
5396·2	5396·2		8sc		5023·9			6sd	
5380·3	5380·3		6nc		5021·3			6sd	
5368·9			8sc		5019·5	5019·5		8sd	
5350·6			8sc		5015·4	5015·7		8sd	
5336·9	5336·9		10sc		5013·4	5013·7	(5013·4)	10sc	r
5298·6			6sd		5012·3			4sd	
5296·8			10sc		5006·7	5006·6	(5006·7)	10sc	r
5295·6			6sd		5001·1			4sd	
5287·9			4sd		4998·9	4998·7	(4998·9)	10sc	r
5282·9			10sc		4990·4	4990·5	(4990·4)	10sc	r
5271·6			4sd		4988·4			6sd	
5267·3			4sd		4981·1	4981·1	(4981·1)	10sc	r
5265·1			8sc		4977·9			6sd	
5263·0			4sd		4975·3			4sd	
5259·7			4sd		4972·3			2sd	
5255·1			4sd		4967·8			2sd	
5251·0			4sd		4964·6			2sd	
5246·5			8nc		4947·1			2sd	
5238·7			8nc		4937·3			8sc	
5226·2			6sd		4927·6			8sc	
	5224·8				4925·1			4sd	
	5224·2				4920·9			6sd	
5223·2		(5223·2)	10nc	r	4919·1			6sd	
5217·7			4sd		4913·3			6sd	
5209·7	5209·7	(5209·7)	10nc	r	4911·4			6sd	
5205·7			6sd		4904·0			4sd	
5200·7			6sd		4899·4			8sc	
5192·5	5192·5	(5192·5)	10sc	r	4884·6	4884·6		10sc	
5188·5			8sd		4873·1			4sd	
	5187·6				4869·1			8sc	
5185·3			6sd		4867·6			8sc	
5173·2			8sc		4855·1			8sc	
5153·5			6sd		4848·1			6sd	
5151·4			8sc		4840·1			8sc	
5147·2			6sd		4835·1			4sd	
5144·7			6sd		4819·6			8nc	

TITANIUM—*continued.*

I. Spark Spectrum	II. Arc Spectrum		Intensity and Character		I. Spark Spectrum	II. Arc Spectrum		Intensity and Character	
Thalén	Ångström	Liveing and Dewar	I.	II.	Thalén	Ångström	Liveing and Dewar	I.	II.
4804·4	4804·4		10sc		4457·6	4457·5		8sd	
4797·6			4sd		4455·1	4455·1		8sd	
4791·7			8sc		4452·6	4452·6		8sd	
4779·1			6sd		4449·6	4449·6		8sd	
4758·6	4758·6		10sc		4446·6	4446·6		8sd	
4757·1	4757·1		10sc		4443·1	4443·1		10nc	
4741·9	4741·9		8sd		4426·9	4426·9		10nc	
4722·9	4722·9		8sd		4417·9	4417·9		8nd	
4709·1	4709·1		8sd		4411·1	4411·1		6sd	
4698·1	4698·1		8sd		4403·1	4403·1		6sd	
4690·7	4690·7	4690·5	8sd	r	4398·6	4398·6		6sd	
4681·6	4681·0	(4681·6)	8sc	r	4393·1	4393·1		10nc	
4666·6	4666·6	4666·5	8sd	r	4337·5			10sc	
4656·1	4656·1	4655·5	10nc	r	4323·5	4323·5		8nd	
4644·1	4644·1		4sd		4320·0	4320·0		2sd	
4638·9	4638·9		10nc		4318·0			2sd	
4629·1	4629·1		6sd		4313·5	4313·5		2sd	
4623·1	4623·1		8sd		4312·5	4312·5		2sd	
4616·8	4616·8	(4616·8)	8sc	r	4307·5	4307·5		2sd	
4571·6	4571·6		10nc		4305·0	4305·0	(4305·0)	8sc	r
4563·3	4563·3		8sd				4299·5		r
4555·4	4555·4		6sd		4299·0	4299·0	4299·0	10nc	r
4551·9	4551·9		6sd				4298·0		r
4549·0	4549·0		10nc		4295·0	4295·0	4295·0	2sd	r
4543·6	4543·6		6sd		4293·8			2sd	
4535·6 }	4535·6 }	4533·2	10nc	r	4290·7	4290·7	(4290·7)	8sc	r
4532·1 }	4532·1 }	4531·7		r	4287·0	4287·0		2sd	
4526·2	4526·2		10sd		4282·0			2sd	
4522·0	4522·0		6sd		4273·0	4273·0		2sd	
4517·6	4517·6		6sd		4263·0	4263·0		8sc	
4511·6	4511·6		6sd		4236·5	4236·5		8sc	
4500·8	4500·8		10nc		4185·0	4185·0		6sd	
4496·2	4496·2		8nd		4171·0	4171·0		10nc	
4481·1			6sd		4163·0	4163·0		10nc	
4468·6	4468·6		10sc						

Arc Spectrum	Intensity and Character	Arc Spectrum	Intensity and Character	Arc Spectrum	Intensity and Character	Arc Spectrum	Intensity and Character
Lockyer		Lockyer		Cornu		Cornu	
3998·7		3933·2		3509·9		3235·0	
3998·0		3929·0		3504·3		3232·7	
3989·2(1)		3925·5		3392·8		3228·0	
3981·5(2)		3923·7(2)		3386·2		3223·1	
3980·8(1)		3920·5(3)		3382·0		3221·7	
3963·3(2)		3919·1(8)		3371·2		3216·9	
3961·7(2)		3913·6(3)		3359·3		3215·8	
3957·2(1)		3912·7		3347·0		3201·7	
3955·3		3910·4(5)		3346·8		3190·2	
3947·7(1)		3904·2		3339·7		3163·0	
3946·8		3900·5(3)		3338·2		3162·4	
3937·2(5)		3900·0(3)		3240·4		3161·9	
				3237·5			

* Double.

Tungsten.

Spark Spectrum Thalén	Intensity and Character	Spark Spectrum Thalén	Intensity and Character
5805·1	4sd	5007·1	6sd
5733·1	6sd	4981·1	4sd
5648·1	4sd	4887·6	8sc
5631·6	2sd	4842·1	10sc
5513·1	10sc	4680·6	2sd
5491·6	8sc	4660·6	2sd
5223·2	10sc	4659·6	2sd
5070·6	6sd	4302·0	6sd
5068·1	6sd	4295·0	6sd
5053·1	10sc	4269·0	6sd
5014·1	6sd		

Lockyer has observed the following lines in the arc spectrum of Tungsten between wave-lengths 3900 and 4000 :—3982·4, 3979·8, 3978·3, 3963·9, 3954·2, 3952·1, 3934·0.

Uranium.

Spark Spectrum		Intensity and Character	Spark Spectrum		Intensity and Character
Thalén	Lockyer		Thalén	Lockyer	
5913·1			4731·1		
5619·1			4723·1		
5579·1			4543·1		
5562·6			4472·6		
5527·1			4393·6		
5509·1			4374·1		
5493·6			4362·1		
5481·6			4340·6		
5479·6				3965·0	
5477·1				3961·7	
5474·6				3943·0	
5384·1				3931 0	
5027·1					

Lockyer has observed the following lines in the arc spectrum of Uranium between wave-lengths 3900 and 4000 :—3997·8, 3996·6, 3995·3, 3994·2, 3993·6, 3993·1, 3991·9, 3988·2, 3985·1, 3983·4, 3983·0, 3979·9, 3978·1, 3977·2, 3976·0, 3974·2, 3973·2, 3971·2, 3970·7, 3969·5, 3965·5, 3961·7, 3958·2, 3954·2, 3953·6, 3952·5, 3951·9, 3951·3, 3950·4, 3947·4, 3942·7, 3941·8, 3941·5, 3939·3, 3934·3, 3931·0, 3929·7, 3927·0, 3925·8, 3925·2, 3922·0, 3920·5, 3920·2, 3916·7, 3915·9, 3915·2, 3914·3, 3913·6, 3911·0, 3910·5, 3908·2, 3907·8, 3906·0, 3903·7, 3901·8, 3901·6.

Vanadium.

Spark Spectrum		Intensity and Character	Spark Spectrum		Intensity and Character
Thalén	Lockyer		Thalén	Lockyer	
6240·7		6sd	5706·1		
6134·6			5702·6		
6119·2			5697·6		
6109·7			5668·1		
6089·2			5626·1		
6080·2			5622·6		
6039·2			5414·1		
5786·1			5401·1		
5725·1			5240·1		

VANADIUM—*continued.*

Spark Spectrum		Intensity and Character	Spark Spectrum		Intensity and Character
Thalén	Lockyer		Thalèn	Lockyer	
5233·2			4406·0		
5195·2			4400·5		
5191·7			4395·0		
4881·1			4389·0		
4874·6			4384·0		
4864·1			4379·0		
4851·1			4352·5		
4843·1			4340·5		
4831·6			4332·5		
4593·1			4329·5		
4585·1			4310·0		
4579·1			4297·0		
4576·1			4292·5		
4459·1			4283·5		
4576·1			4277·0		
4459·1			4272·0		
4407·6			4268·5		
4406·1			4110·0		
4400·6				3997·9	
4395·1				3992·5	
4389·1				3989·6	
4384·1				3923·7	
4379·0				3913·6	
4576·0				3909·3	
4459·0				3901·3	
4407·5					

Lockyer has observed the following lines in the arc spectrum of Vanadium between wave-lengths 3900 and 4000 :—3998·0, 3996·6, 3994·1, 3992·1, 3989·8, 3988·2, 3983·8, 3983·6, 3979·7, 3978·7, 3978·3, 3976·8, 3974·5, 3972·5, 3971·2, 3967·0, 3962·7, 3950·9, 3949·4, 3947·5, 3942·7, 3941·2, 3940·3, 3938·1, 3937·2, 3936·7, 3935·0, 3933·8, 3933·0, 3930·2, 3929·0, 3927·0, 3924·4, 3923·7, 3921·6, 3919·6, 3913·6, 3912·2, 3911·6, 3900·5, 3910·2, 3909·2, 3906·2. 3901·6, 3900·5.

YTTERBIUM.

Spark Spectrum	Intensity	Spark Spectrum	Intensity	Spark Spectrum	Intensity
Thalén		Thalén		Thalén	
6489·0	2	5766·0	2	5431·7	4
6463·0	2	5749·5	1	5426·5	2
6274·0	2	5736·0	2	5414·0	2
6261·0	1	5729·5	2	5389·0	1
6221·0	10	5718·5	4	5367·0	1
6199·0	1	5651·0	4	5363·0	1
6159·5	4	5630·5	1	5352·0	10
6151·5	4	5619·5	2	5346·5	8
6054·0	1n	5587·5	4	5345·0	8
6004·0	6	5580·0	1	5334·0	10
5990·0	4	5559·5	1	5300·0	4
5983·5	6	5555·5	10	5279·0	4
5944·0	4	5536·0	2	5276·0	2
5907·0	1	5528·5	2	5257·0	4
5836·0	6	5476·0	10	5243·0	2
5818·0	6	5453·0	2	5239·5	2
5770·0	4	5447·5	4	5226·0	1

YTTERBIUM—*continued.*

Spark Spectrum Thalén	Intensity	Spark Spectrum Thalén	Intensity	Spark Spectrum Thalén	Intensity
5217·5	1n	4785·5	8	4513·0	2
5183·5	2	4725·0	8	4493·0	1
5134·7	2	4682·5	2	4438·5	2
5085·0	2	4597·5	1	4316·5	1
4993·5	4	4582·0	1	4218·0	1
4936·5	2	4575·5	4	4183·0	1
4935·0	6	4518·0	4	4180·0	2

YTTRIUM.

Spark Spectrum Thalén	Intensity and Character	Spark Spectrum Thalén	Intensity and Character	Spark Spectrum Thalén	Intensity and Character
6613·0	6	5502·5	4	4397·0	4
6434·5	8	5496·0	10	4374·0	10
6313·0	1	5479·5	6	4359·0	2
6296·0	1	5473·0	6	4309·0	10
6236·0	2	5468·3	1	4236·5	4
6217·5	4	5466·0	8	4176·5	8b
6206·0	1	5437·0	4	4167·0	6
6190·5	10	5423·5	2	4142·5	4
6181·0	6	5416·0	1	4127·0	4
6163·5	8	5402·0	10	4102·5	2
6149·0	8	5379·0	2		
6137·0	1	5320·0	2		
6131·0	10	5288·0	4	Arc Spectrum	
6126·0	1	5205·0	10		
6114·0	2	5199·5	10	Lockyer	
6106·5	2	5195·5	4		
6095·0	2	5122·5	8	3999·8	
6088·0	1	5118·0	6	3997·8	
6071·0	2b	5087·5	10	3996·1	
6036·0	4	4981·5	4	3991·0	
6022·5	1	4973·0	1	3987·4	
6018·5	6	4881·0	10	3982·7	
6008·5	6	4859·0	2	3981·7	
6002·5	8	4854·0	10	3981·0	
5986·5	10	4852·0	2	3978·7	
5774·0	4	4844·0	2	3977·9	
5742·5	2	4838·5	2	3973·8	
5705·5	1	4822·0	4	3972·0	
5674·0	1	4799·0	2	3962·1	
5662·0	10	4760·5	4	3952·4	
5647·0	2	4751·0	4	3950·6	
5643·0	2	4732·0	1	3949·4	
5604·5	6	4728·0	1	3947·2	
5576·0	6	4681·5	4	3944·6	
5566·5	2	4657·5	1	3943·7	
5544·5	6	4643·0	8	3943·5	
5543·0	6	4526·5	6	3937·8	
5526·5	8	4505·0	4	3936·3	
5520·0	6	4486·0	2	3933·8	
5512·0	1	4464·5	1n	3930·0	
5509·0	8	4422·0	8	3915·7	
				3906·0	

Zinc.

I. Spark Spectrum				II. Arc Spectrum		Intensity and Character	
Huggins	Thalén	Kirchhoff	Mascart	Liveing and Dewar	Cornu	I.	II.
6581							
*6360	†6362·8[4]	6363·2	6360·7				
6211							
6100	†6102·2[1]	6102·1					
6041							
	†6022·7[1]	6022·2					
5910							
5894	†5893·6[2]	5893·6					
5814	†5816·1[2]						
5755	†5756·1[1]						
5741	§†5745·1[1]						
	‡5608·1						
5577	†5577·6[1]						
5563	†5563·1[1]						
	‡5465·6						
	†5436·1[1]						
5333	†5336·1[1]						
5247	†5249·7[1]						
5232	†5233·2[1]						
5157	†5158·7[1]						
5122	†5121·1[1]						
5117							
5083							
5072	†5074·1[1]						
5049	†5048·1[1]						
4970	†4971·1[1]						
4924	†4923·9[3]	4926·2	4923·2	not seen			
4911	†4911·3[3]	4911·5	4910·5				
	†4878·1[1]						
4867	†4865·1[1]						
*4809	†4809·8[4]	4810·1	4809·0	(4809·8)			r
*4722	†‖4721·5[4]	¶4721·4	4720·6	(4721·4)			r
*4679	†‖4679·6[4]	¶4679·8	4678·5	not seen			
		Hartley and Adeney					
		3813·5				1sd	
		3811·5				1sd	
		3757·5				2sd	
		3720·5				4sd	
		3713·5				1	
		3704·5				4sd	
		3694·0				4sd	
		3683·0				4sd	
		3668·0				4sd	
		3645·4				2sd	
		3632·2				4sd	
		3623·4				4sd	
		3578·2				2sd	
		3560·8				2sd	
		3536·8				1sd	
		3529·8				2sd	
		3509·2				1sd	
		3491·8				2sd	

ZINC—*continued.*

I. Spark Spectrum	II. Arc Spectrum		Intensity and Character	I. Spark Spectrum	II. Arc Spectrum		Intensity and Character
Hartley and Adeney	Liveing and Dewar	Cornu	I.	Hartley and Adeney	Liveing and Dewar	Cornu	I.
3344·4	3342·0		10nc	2479·2	2480·0		2sd
3301·7	3301·0		10nc	2472·2			4sd
3281·7	3281·0		8nc	2468·3			2sd
3255·8			2sd	2465·9	2464·5		4sd
3238·7			2sd	2462·8			2sd
3234·6			2sd	2461·3			4sd
3075·6			8sc	2459·8			2sd
3071·7	3070·0		8sd	2450·0			4sd
3035·4	3035·0		8sd	2441·6	2440·0		4sd
3024·1			2sd	2437·7			4sd
3017·5	3017·0		4sd	2433·9			2sd
2996·7			2sd		2430·0		
2959·5			2sd	2427·0			8sd
2886·4			2sd	2423·3			4sd
2856·3			2sd	2420·7			2sd
2800·1	2800·0		8nc	2418·8			8sd
2782·5			1sd	2408·4			4sd
2778·4			2sd	2405·3			4sd
2770·2	2770·0		8nc	2401·9			1sd
2754·5	2756·0		7nd	2398·7			1sd
2719·7			2sd	2396·4			1sd
2711·5	2713·3		2sc	2393·3			1sd
2683·8	2684·0		2sc	2390·1			1sc
	2670·5			2384·2			1sd
2657·0			2sd	2382·8			1sd
2607·6	2608·5		4sd	2371·7			1sd
2592·3			1sd	2367·8			1sd
2589·3			1sd	2348 7			4sd
2585·1			1sd	2346·7			1sd
2581·4	2582·0		4sd	2329·3			1sd
2574·8			4sd	2315·0			4sd
2569·4	2569·7		4sd	2308·8			4sd
2557·3			10nc	2267·0			2sd
2535·0			2sd	2255·0			2sd
2532·3			2sd	2138·5		2138·5	4nc
2526·3			8sd	2104·2			2sd
2521·3			8sd	2102·0			2sd
2514·7	2516·0		8sd	2099·0		2098·8	1nc
2508·7			8sd	2095·9			2sd
2501·5			10nc	2085·4			2nd
2497·0			1sd	2077·6			1sc
2496·5			1sd	2068·4			1sd
2490·4	2491·5		8nd	2062·8		2063·4	1nd
2485·9			8nd	2060·8		2061·0	1nc
2485·0			4sd	2024·2		2024·3	1nc
2483·7			2sd				

* Observed also by Lecoq de Boisbaudran in the Spark Spectrum of Zinc Chloride solution, who has also noted lines at 5184 and 4630.

† Observed also by Lockyer. The 'indices' attached to these numbers denote the comparative 'lengths' of the lines as given by Lockyer.

§ 5739 G. Johnstone Stoney.

‡ 'Could not be identified,' Lockyer.

‖ Observed also in the Arc by Ångström.

¶ 4725·0 and 4680·0, Hartley and Adeney.

ZIRCONIUM.

I. Spark Spectrum	II. Arc Spectrum	Intensity and Character	
Thalén	Lockyer	I.	II.
6343·8		6sd	
6310·3		6sd	
6140·7		10sc	
6132·7		6sd	
6127·2		10sc	
5384·6		4sd	
5349·6		6sd	
5190·7		6sd	
4815·1		10sc	
4771·1		10sc	
4738·6		10sc	
4709·6		10sc	
4686·6		10sc	
4497·6		4sd	
4494·6		4sd	
4443·1		4sd	
4380·1		4sd	
4370·0		4sd	
4360·0		4sd	
4242·0		4sd	
4241·5		4sd	
4228·5		4sd	
4209·5		4sd	
4209·0		4sd	
4155·0		8sc	
4149·0		8sc	
	3998·5		
	3990·4		
	3989·0		
	3988·2		
	3984·1		
	3980·6		
	3978·1		
	3976·8		
	3974·5		
	3972·7		
	3971·5		
	3965·7		
	3962·8		
	3957·2		
	3940·7		
	3935·0		
	3933·8		
	3933·0		
	3928·6		
	3920·8		
	3915·9		
	3915·2		
	3906·0		
	3900·0		

WAVE-LENGTH TABLES OF THE SPECTRA OF COMPOUNDS.

Ammonia.

Flame Spectrum		Intensity and Character	Flame Spectrum		Intensity and Character
Dibbits	Lecoq de Boisbaudran		Dibbits	Lecoq de Boisbaudran	
(1) 6629		$1b^v$	ζ {5807		3s
α {6629		5s	5754		3s
6542		5s	η 5705	α 5702	8n
(2) 6420		$1b_{17}$	{5664		5s
	γ {6325	n	(4) 5617		$2b_9$
	6293		(5) 5466	δ 5470	$2b^v_9$
β 6302		$6b_4$	θ 5382		8s
γ {6227		2n	(6) 5330		$6b^r$
6185	η 6180	5n	ι *5284	ε 5252	$8b_1^v$
6117		2n	(7) 5158		$8b^v$
δ 6036	β {6045	7n	κ 5128		$7b^r$
	6008	6n	λ 5079		$4b_4^r$
ε {5982		6s	(8) 4997		$7b_4^r$
5970	ζ 5964	5n	μ 4782		$4b_{17}^r$
(3) 5834		$1b_{13}$			

* Double.

The spark spectrum of ammonia, according to Lecoq de Boisbaudran, shows one broad band at 5657 (5656·5 Schuster) which, with a finer slit, is resolved into two bands, 5681 of intensity 7, and 5643 of intensity 8 (5686 to 5627 Schuster). Lecoq de Boisbaudran obtained the 'Flame Spectrum' also by use of the spark; its production appears to depend upon the presence of oxygen.

Aluminium Oxide.

Lecoq de Boisbaudran	Thalén	Lockyer	Intensity and Character
5457			3n
		5438·5	
		5428·5	
		5417·5	b
δ 5408	5409·8	5408	1s
5391	5395·4	5397	2s
5373	5377·8		3s
5354	5357·4		4s
5331	5333·6		4s
5190	5186·8	5191	1s
5175		5180·5	2s
5161	5160·4	5166	5b
		5154·5	
β 5145	5141·4		6b
		5139·5	
5124	5123·8	5121	8b
5103	5102·2	5100·5	9b
5080	5075·4	5080	9b
		4930·5	
α {4891	{4890·2	4901	3b
4871	4864·2		8b
4845	4839·0		10b

Aluminium Oxide—*continued.*

Lecoq de Boisbaudran	Thalén	Lockyer	Intensity and Character
		4739·5	
γ { 4719	{ 4711·2	4714·5	1n
4698	4690·0	4694·5	3n
4675	4670·6	4673	4b
4652	4649·0	4645	6b
{ 4567			1n
4544			1n
4522			1n
4500			2n
4478			1n

Barium Chloride.

Flame Spectrum		Intensity and Character
Lecoq de Boisbaudran	Mitscherlich	
γ 5313	5314	$8b_2$
α 5242	5245	$10b_2$
δ { 5205	5209	3n
5171	5177	4n
β 5136	5144	$9b_2$
ε 5064	5112	3n
	5076	

Barium Bromide.

Flame Spectrum		Intensity and Character
Lecoq de Boisbaudran	Mitscherlich	
γ 5410	5393	$8b_2$
α 5358	5356	$9b_2$
δ { 5304	5312	$6b_1$
5249	5259	$6b_1$
β 5206	5217	$9b_2$
ε 5149	5179	$4b_1$
5102		$2b_2$

Barium Iodide.

Flame Spectrum		Intensity and Character
Mitscherlich	Lecoq de Boisbaudran	
5599	α 5607	$9b_2$
5384	β 5376	$9b_1$

Barium Oxide.

Flame Spectrum Lecoq de Boisbaudran	Intensity and Character	Flame Spectrum Lecoq de Boisbaudran	Intensity and Character
6819	1n	5768	$4b_3$
λ 6499	$5b_7^{\blacktriangledown}$	η 5719	$8b_3$
6448	2n	5647	$8b^{\blacktriangledown}$
ζ 6297	8n	5613	2n
6239	4b	[α *5536	9s]
γ 6178	5b	δ 5492	$9b_4^{\blacktriangledown}$
6108	8b	5461	1n
6031	$9b^{\blacktriangledown}$	ε 5346	$8b_7^{\blacktriangledown}$
5995	2n	θ 5215	$8b_5^{\blacktriangledown}$
β 5938	1b	ι 5089	$7b_8^{\blacktriangledown}$
5867	$9b^{\blacktriangledown}$	5019	$2b_3$
μ 5824	$5b_4$	4974	$2b_2$
		κ 4873	$6b_5$
		4794	$1b_2$

* Due to the *metal* itself.

Bismuth Chloride.

Mitscherlich	Intensity	Mitscherlich	Intensity
6582	1	5717	6
6499	1	5681	6
6472	2	5650	5
6406	2	5625	5
6359	2	5593	5
6312	2	5527	4
6270	3	5527	4
6226	3	5494	4
6182	3	5459	4
6140	3	5428	4
6095	4	5398	3
6050	4	5370	3
6018	4	5320	3
5976	4	5286	3
5932	5	5232	3
5886	5	5207	3
5834	6	5184	2
5795	6	5156	2
5756	6	5139	2
		5109	1

Bismuth Oxide.

Mitscherlich	Intensity	Mitscherlich	Intensity
6382	$b^{\blacktriangledown}$	5582	$b^{\blacktriangledown}$
6194	$b^{\blacktriangledown}$	5444	$b^{\blacktriangledown}$
6039	$b^{\blacktriangledown}$	5328	$b^{\blacktriangledown}$
5873	$b^{\blacktriangledown}$	5220	$b^{\blacktriangledown}$
5717	$b^{\blacktriangledown}$		

Boron Trioxide.

Flame Spectrum			Intensity and Character
Thalén	Lecoq de Boisbaudran	Salet	
	6397	6400	$3b_1$
	6210	6210	$4b_2$
	6031	6030	$3b_2$
5781	δ 5807	5800	$7b_3$
5473	α { 5480	5480	9n
	α { 5439		$2b_2$
5188	β 5192	5200	$8b_6$
4957	γ 4941	4910	$7b_7$
	ε 4721	4700	$5b_8$
	4529	4540	$3b_8$

Calcium Chloride.

Flame Spectrum Lecoq de Boisbaudran	Intensity and Character	Flame Spectrum Lecoq de Boisbaudran	Intensity and Character
6442	$5b_5$	β 5933	$9b_2^r$
ε { 6348	2n	ζ 5817	5n
ε { 6320	2n	5728	2n
η 6265	9n	†δ { 5543	$6b_3^r$
α { 6202	10s	†δ { 5517	$4b_2^r$
α { 6181	10s	[*4226	3s]
γ { 6068	7s		
γ { 6044	6s		

* Due to the metal. † Probably due to the oxide.

Calcium Bromide.

Mitscherlich	Intensity and Character
6266	6s
6242	6s
6102	4s

Calcium Fluoride.

Mitscherlich	Intensity and Character
6060	4s
6026	4s
5328	5n
5301	5n

Calcium Iodide.

Mitscherlich	Intensity and Character
6270	6s
6252	6s
6177	4s

Calcium Oxide.

Lecoq de Boisbaudran	Intensity and Character
β 6220	$4b_{12}$
5995	$3b_2$
γ 5543	$6b_3^{v}$
α 5517	$4b_2^{v}$

Carbon Oxide.

Watts	Ångström and Thalén	Piazzi-Smyth and Herschell	Intensity and Character
	6853		1b
	6748		1b
	6622·0		$3b^r$
	6462		1b
6060	6078·0		$4b^r$
	5900		1b
	5817·0		$3b^r$
	5689		1b
5610·5	5607·5	5612·0	$5b^r$
		5608·8	5b
		5607·0	5b
		5605·5	5b
	Fine lines too close to measure	5603·9	4b
		5602·0	4b
		5597·9	4b
		5595·9	4b
	5591·8	5593·4	3b
	5588·3	5590·8	3b
	5585·5	5587·6	3b
	5582·5	5584·5	3b
	5578·5	5580·6	2b
	5574·0	5577·2	2b
	5570·5	5573·0	2b
	5566·5	5568·6	2b
	5562·2	5563·9	1b
	5557·5	5559·0	1b
		5553·9	
		5548·4	
		5542·6	
		5536·7	
		5530·8	
		5524·4	
		5518·5	
		5511·6	
		5505·4	

CARBON OXIDE—*continued.*

Watts	Ångström and Thalén	Piazzi-Smyth and Herschell	Intensity and Character
		5498·2	
		5490·9	
		5483·2	
		5475·7	
		5467·9	
		5461·4 ?	
		5454·0 ?	
	5449		1b
		5444 ?	
	5397·5		3b^r
	5370		1b^r
	5265		1b
5198·4	5197·0		
		5198·7	4b^r
		5198·2	6b^r
		5197·7	6b^r
		5197·2	4b^r
		5196·3	2
		5195·7	5
	Fine lines too close to measure	5195·0	5
		5194·2	2
		5193·1	2
		5192·3	2
		5191·8	2
		5191·2	2
		5190·5	4
		5190·0	4
	5186·5	5188·8	6
		5188·7	6
		5186·9	12
	5183·5	5184·9	6
		5184·3	6
	5181·5	5182·5	5
		5181·7	5
	5178·5	5180·1	5
		5179·2	5
	5175·0	5177·1	5
		5176·4	5
	5172·5	5174·1	5
		5173·0	5
	5169·5	5170·9	5
		5169·6	5
	5166·2	5167·5	5
		5166·7	2
		5165·9	2
		5165·5	2
		5165·2	2
		5164·6	2
	5162·0		
	5015·0		1b^r
4836·6	4833·5	4836·5	5b^r
	Fine lines too close to measure		
	4822·5		4b
	4820·3		4b
	4818·1		4b
	4816·0		4b

Carbon Oxide—*continued.*

Watts	Ångström and Thalén	Piazzi-Smyth and Herschell	Intensity and Character
	4813·5		3b
	4811·0		3b
	4808·6		3b
	4805·7		3b
	4802·8		2b
	4799·4		2b
	4796·0		2b
	4792·5		1b
	4788·8		4b
	4785·5		4b
	4780·6		1b
	4776·4		1b
	4772·2		1b
	4767·8		2b
	4762·8		2b
	4757·7		1b
	4753·0		3b
	4748·0		3b
	4697·0		$2b^r$
	4630		$1b^r$
	4568		1b
4505	4509·0	4516·9	$5b^r$
4395	*4394·0	4393·0	$4b^r$
	4292		1b
	4209·0		1b
	4131·0		$3b^r$

* At the negative pole this band appears slightly displaced towards the blue—and of equal intensity throughout—not sharp towards the red.—Schuster.

Carbon Nitride.

Dibbits	Mitscherlich	Watts	Plücker and Hittorf	Liveing and Dewar	Lockyer	Intensity and Character
[1]7080	7102		6800			$2b_7$
[2]6906	6938		6700			$8b^v$
[3]6657	6670		6495·4			$7b^v$
[4]6486	6477		6426·7			$5b^v$
[5]6334	6344		6312·3			$5b^v$
[6]6193	6200		6206·2			$5b^v$
[7]6010	6022					$4b^v$
[8]5892	5888					$4b^v$
[9]5750	5746					$4b^v$
	5632					$3b^v$
	5498					$2b^v$
	5389					$2b^v$
	5245					$1b^v$
4609	4607	4600	(4600)	4600		$10b^r$
4583	4582	4574	4571·5	4574		$10b^r$
4559	4548	4550	4548·5	4550		$9b^r$
4537	4526	4534	4526·1	4532		$9b^r$
4521	4505	4514	4508·2	4515		$8b^r$
4508		4505	4495·3	4505		$7b^r$
4500		4502	4490·8	4500		$6b^r$

CARBON NITRIDE—*continued.*

	Dibbits	Mitscherlich	Watts	Plücker and Hittorf	Liveing and Dewar	Lockyer	Intensity and Character
				4377·0	*4381·5		
				4367·1	*4371·5		
				4361·3	*4364·5		
	4208	4212	4220	(4215·6)	4218	4215·6	10bʳ
						4210·0	
						4199·9	
	4188	4197	4210	4199·6	4205	4197·2	10bʳ
						4191·0	
						4187·4	
						4186·5	
						4186·4	
						4184·4	
						4183·5	
						4182·6	
						4182·2	
	4171	4182	4190	4183·3	4192	4180·4	9bʳ
						4178·7	
θ						4177·8	
						4176·6	
						4175·8	
						4174·4	
						4173·5	
						4172·6	
						4171·4	
						4169·7	
						4168·8	
						4168·8	
	4155	4170	4174	4166·5	4176	4167·2	8bʳ
						?	
	4147	4159	4166	4156·1	4165	4157·5	8bʳ
						?	
	4142	4147	4160	4150·2	4158	4151·5	7bʳ
			4158			?	
		4136				4144·1	6bʳ
	3854	3859			3882·7	3882·8	10bʳ
						?	
	3839	3847			3871	3870·6	9bʳ
						?	
						3867·1	
						3866·4	
						3865·4	
						3864·8	
ι						3863·9	
						3863·1	
						3862·2	
	3827	3839			3862	3861·6	8bʳ
						3860·8	
						3859·8	
						3859·2	
						3858·3	
						3858·0	
	3815				3854·5	3857·5	7bʳ
						3856·6	
						3856·0	
						3855·4	

* 'Probably not connected with the presence of nitrogen.'—LIVEING & DEWAR, 'Proc. Roy. Soc.,' No. 223, 1882.

CARBON NITRIDE—*continued.*

Dibbits	Mitscherlich	Watts	Plücker and Hittorf	Liveing and Dewar	Lockyer	Intensity and Character
				3850		$6b^r$
				3589		$10b^r$
				3583		$9b^r$
				3360		$10b^r$
				2718 &c.		b^r
				2588 &c.		b^r
				2479 &c.		b^r
				2373 &c.		b^r

CHROMIUM CHLORIDE.

Spark Spectrum — Lecoq de Boisbaudran	Intensity and Character	Spark Spectrum — Lecoq de Boisbaudran	Intensity and Character
6393	$3b_8^v$	5566	$3b_4^v$
6048	$3b_8^v$	*4649	2n
5790	$3b_7^v$	4343	$1b_2$
5622	$2b_6^v$		

* Double.

COPPER CHLORIDE.

	Flame Spectrum — Lecoq de Boisbaudran	Intensity and Character		Flame Spectrum — Lecoq de Boisbaudran	Intensity and Character
	6618	$6b_6$		5148	$5b^v$
η	6267	$8b_{16}^v$	κ	5087	$7b^v$
ζ	6150	$9b_7^v$	κ	5049	$8b^v$
ζ	6143	2s	ϵ	4983	$9b_5^v$
ζ	6050	$9b_5^v$	ϵ	4945	$8b_5^v$
ζ	6041	1s	δ	4882	$9b_5^v$
	5807	1n	δ	4847	$9b_2^v$
	5780	2s	λ	4792	$7b_5^v$
	5728	5n	λ	4757	$5b_2^v$
	5670	4n		4704	$2b_4^v$
	5629	4n		4674	$2b_3$
	5563	$7b_4$		4612	$2b_3^v$
α	5506	10n		4579	$6b_2^v$
α	5489	3n	θ_1	4522	$8b_5^v$
α	5463	5n	θ_1	4496	$8b_2^v$
α	5439	9s	γ_1	4436	$9b_5^v$
α	5422	2s	γ_1	4412	$9b_2^v$
α	5405	4s	γ_2	4353	$9b_4^v$
α	5385	10n	γ_2	4331	$8b_1^v$
	5355	4n	θ_2	4281	$7b_4^v$
ι	5305	8b	θ_2	4260	$6b_1^v$
β	†5260	$9b_2^v$		4217	$3b_3^v$
	5239	7n		4192	$1b_1^v$
	5210	$2b_7$		4125	$1b^v$

† Becoming 5269 – b.

Copper Bromide.

Mitscherlich	Intensity and Character	Mitscherlich	Intensity and Character
5215	b^v	4537	.b^v
5124	b^v	4515	b^v
5033	b^v	4462	b^v
4949	b^v	4447	b^v
4872	b^v	4405	b^v
4823	b^v	4384	b^v
4619	b^v	4340	b^v
4593	b^v	4320	b^v

Copper Iodide.

Mitscherlich	Intensity and Character	Mitscherlich	Intensity and Character
5393		5073	
5314		5018	
5232		4959	
5144		&c.	

Copper Oxide.

Flame Spectrum	Intensity and Character
Lecoq de Boisbaudran	
5370	$6b_{37}$
5106	$2b_{17}$
4946	$2b_{16}$

Erbium Oxide.

Flame Spectrum		Intensity and Character	Flame Spectrum		Intensity and Character
Bunsen	Lecoq de Boisbaudran		Bunsen	Lecoq de Boisbaudran	
6519	δ { 6609	7n	5230	α { 5228	$9b_2$
	δ { 6546	8n		α { 5204	9n
	6492	3n		5123	$2b_4$
	6404	$1b_7$		5038	$1b_3$
	γ 5631	$8b_4$	4867	η 4910	$4b_8$
	θ 5514	$4b_{10}$		4756	$1b_4$
	5413	2n		ε 4648	$6b_5$
5404	β 5387	$9b_2$		4568	$2b_6$
	5346	$3b_2$		ζ 4500	$5b_4$
	5264	$4b_2$			

Erbium Phosphate.

Flame Spectrum — Lecoq de Boisbaudran	Intensity and Character	Flame Spectrum — Lecoq de Boisbaudran	Intensity and Character
6913	$1b_{11}$	5391	$2b_3$
6694	$5b_{10}$	β { 5238	9n
6597	7n	5208	9n
α 6526	$9b_4$	4928	$6b_5$
ε 6432	$7b_5$	4878	$7b_3$
γ { 5507	$7b_1$	4567	$5b_{11}$
5463	$8b_1$		

Gold Chloride.

Flame Spectrum — Lecoq de Boisbaudran	Intensity and Character	Flame Spectrum — Lecoq de Boisbaudran	Intensity and Character
5913	$4b_{11}$	β_2 { 5179	2n } b_8^v
ε 5752	$6b_{11}$	5158	7n
γ 5600	$8b_1$	5141	4s
β_1 { 5477	3s } b_7	5125	9n
5458	9n	δ { 5102	8n } b_7^v
5437	5s	5080	6n
5418	4s	5063	3s
α_1 { 5364	5s } b_8^v	5044	6n
5348	9n	5030	$4b_7^r$
5328	6n	4516	$2b_{10}$
5311	9n	4430	$2b_4$
α_2 { 5286	4n		
5263	9n } b_9^v		
5244	4n		
5222	9n		
5210	6n		

Hydrogen Oxide. *See* 'Water.'

Iron Oxide.

Mitscherlich	Intensity and Character	Mitscherlich	Intensity and Character
6219	$1b^v$	5632	$5b^v$
6182	$2b^v$	5444	$4b^v$
5892	$4b^v$	5420	$2b^v$
5665	$4b^v$		

Lead Oxide.

Mitscherlich	Intensity and Character	Mitscherlich	Intensity and Character
6265	$2b^v$	5144	$4b^v$
6196	$2b^v$	4993	$4b^v$
5997	$2b^v$	4913	$4b^v$
5955	$2b^v$	4880	$3b^v$
5892	$3b^v$	4852	$3b^v$
5665	$4b^v$	4825	$3b^v$
5615	$4b^v$	4664	$2b^v$
5460	$5b^v$	4593	$2b^v$
5414	$5b^v$	4468	$2b^v$
5328	$5b^v$	4381	$1b^v$
5273	$5b^v$	4296	$1b^v$
5220	$4b^v$		

Magnesium Hydride.

Liveing and Dewar	Intensity and Character	Liveing and Dewar	Intensity and Character
5618	$8b^r$	5210	$10b^r$
&c.		&c.	
5566	$8b^r$	5180	$10b^r$
&c.		&c.	
5513	$8b^r$		
5512	$8b^r$	4849	$8b^r$
5511	$8b^r$	&c.	
&c.		4803	$8b^r$
		&c.	

Magnesium Oxide.

Lecoq de Boisbaudran	Watts	Liveing and Dewar	Intensity and Character
5006	5006·5	5000	$8b^r$
4994	4996·5	4990	$7b^r$
4984	4985·7	4980	$5b^r$
4974	4974·7	4969	$4b^r$
4966	4963·7	4957	$2b^r$ b_9^r
4958	4948·7	4945	$2b^r$
	4934	4930	$1b^r$
	4924		$1b^r$
	4914		$1b^r$
		4797	

Manganese Oxide.

Lecoq de Boisbaudran	Watts	Intensity and Character	Lecoq de Boisbaudran	Watts	Intensity and Character
6327		1s	5549		$2b_2^v$
6288		2s	5511		$3b_2^v$
6249		3s	5473		5b
	6234	4s	β	5433	5s
η 6215		4s	5427	5423	$8b^v$ b_{20}^v
	6204	$4b^r$		5395	8s
6187	6185	4s	5398	5391	$9b^v$
	6178	$4b^r$	5367	5359	$9b^v$
6150		3s	5308		$2b_2$
5943		3n	5260		$4b_2^v$
	5932	2s	ε 5223	5229	$6b_2^v$ b_{18}^v
δ 5915		6n	5189	5192	$7b_2^v$
	5909	$1b^v$	5155	5157	$6b_2^v$
5887		7n	5135		1b
5858		6n	5089		$3b^v$
	5847	$2b^v$			
5807		$1b_2^v$			
5759		$2b_2^v$			
5719		$3b_2^v$			
	5688	3s			
	5683	3s b_{27}^v			
α 5676		$4b_2^v$			
	5644	$6b^v$			
5614		$9b^v$			
	5607	$5b^v$			
5587	5580	9n			

Thirteenth Report of the Committee, consisting of Professors J. PRESTWICH, W. BOYD DAWKINS, T. MCK. HUGHES, *and* T. G. BONNEY, DR. H. W. CROSSKEY (*Secretary*), DR. DEANE, *and* Messrs. C. E. DE RANCE, H. G. FORDHAM, J. E. LEE, D. MACKINTOSH, W. PENGELLY, J. PLANT, *and* R. H. TIDDEMAN, *appointed for the purpose of recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England, Wales, and Ireland, reporting other matters of interest connected with the same, and taking measures for their preservation.*

THE Committee have to record the following additional observations. Continuing his previous investigations, Mr. Luff, of Clun (Shropshire) has traced fragments of the Upper Llandovery grit (which are scarcely large enough to be called 'boulders') along a bee line drawn across the map from Clun to Rhayader, twenty-three miles W.S.W. This line passed through Llanbister and Abbey-cwm-hir; crossed at right angles the deep valleys of the Teme and the Ithon, and passed over the extensive Beguildy Mountains and the long transverse range of Cambo Hill. Fragments of grit were found at short intervals the whole of the way,

and two miles south of Rhayader the rocks of Carrig Gwinion present themselves as the source from which they all may have been derived. The specimens were very small—the largest being about one foot cube—and in no respect equal the remarkable assemblage of big blocks, previously described, on the long and high ridge forming the watershed of the Clun and Teme. These fragments of grit, however, occur at considerable heights as well as in the valley bottoms—being found on the top of Beguildy Beacon, more than 1,700 feet above the sea. One block of Rhayader grit has been found north of the Clun river, but as a rule the Clun river forms a northern boundary to this flow in a peculiarly sharp and striking way. A remarkable mixture of boulders occurs. Amongst the western boulders on the Clun Hills are (although few in number) quartzites from the Stiper Stones district fifteen miles north, and about Leebotwood, north of the Longmynd, are granites from Scotland or the Lake district. The flow of quartzites has overlapped and invaded the ground covered by the Plynlimmon stream, and the granites while doing the same with this local dispersion, have crossed the eastern stream of Arenig boulders.

Professor Bonney writes that he is now satisfied, in consequence of information supplied to him by Professor Hughes, that the picrite boulders noticed by him in the Report for 1883 as occurring near the west coast of Anglesey, are derived from masses of rock which occur *in situ* to the north-east, especially from one near Caemawr. He has also received from Dr. H. Hicks specimens of a boulder of very characteristic hornblende picrite, which the latter found lying on 'Dimetian' rock, on the east side of Porthlisky harbour, near St. David's. Its longer axis measured about a yard: in transverse section it was rather triangular, the shorter sides measuring twenty-two inches and sixteen inches respectively. No rock of the kind is known to occur *in situ* anywhere in the district. This is more fully described, and the origin of the Anglesey boulders discussed in a paper by Professor Bonney which has appeared in the 'Quarterly Journal of the Geological Society' (vol. xli. p. 511).

Mr. R. T. Andrews of Hertford has forwarded the Committee a catalogue of blocks from that neighbourhood, showing that the materials generally spread over the north of Herts extend south to the Hertford district. These may be divided into three main groups. (1) Hertfordshire '*Pudding-stone*'; (2) Compact sandstones; (3) Grits and coarse sandstones. The Hertfordshire 'Pudding-stone' is of course locally derived. The fine compact sandstones, with coarser sandstones and grits, are of the kind so common in the boulders of Hertfordshire and the adjacent counties, which have been fully described in the Report of the Committee for 1881. Mr. Fordham remarks upon this catalogue, that the derivation of the rocks cannot be stated with exactness, since there is little about the materials, as found in moderate sized fragments, to identify them with particular beds; but their characteristics generally show that in all probability some of them have been derived from the secondary rocks of the Midlands, while others have come from the millstone grits and other older rocks further north. The absence of igneous rocks in this catalogue will be noted. As igneous rocks are rare in the north of Hertfordshire, their apparent absence in the centre of the county shows that there has been a gradual diminution of igneous material towards the south, while at length in the centre of Hertfordshire they are certainly absent.

Catalogue of Boulders found in the neighbourhood of Hertford.

No.	—	Dimensions	Where found	Remarks
1	Compact Sandstone . .	3′ 0″ × 2′ 6″ × 2′ 0″	Brickendon Green, S.W. of Hertford.	Oblong and flattish; rounded off at one end more than the other; smooth. Height above the sea about 350 ft.
2	Coarse Sandstone or Grit .	2′ 9″ × 2′ 2″ × 1′ 6″	Removed from adjacent field to N. of a barn at Clement's farm.	Smooth.
3	Compact Sandstone . .	1′ 6″ × 1′ 5″ × 1′ 4″	Angle of a pond; Clement's farm.	Height above sea, 230 ft.
4	Herts Pudding-stone .	Fragment	Brickendon Green.	Used for foundations of a shed.
5	,, ,,	,,	,,	,,
6	,, ,,	,,	,,	,,
7	,, ,,	,,	,,	,,
8	,, ,,	3′ 2″ × 2′ 1″ × 1′ 0″	,,	Smooth.
9	Herts Plum-pudding stone	2′ 7″ × 1′ 8″ × 1′ 5″	In garden, Castle Street, Hertford.	Probably removed from elsewhere in neighbourhood.
10	,, ,,	2′ 1″ × 1′ 2″ × 1′ 3″	Castle Street, Hertford. In fernery.	
11	,, ,,	1′ 4″ × 1′ 1″ × 9″	Bayford.	Brought to garden of lodge from a ploughed field.
12	,, ,,	1′ 6″ × 1′ 3″ × 1′ 0″	Tyler's Causeway; inside cottage-garden gate.	Brought from same field as No. 11.
13	,, ,,	2′ 3″ × 1′ 8″ × 9″	Hill going up to Tolmer's Church.	
14	,, ,,	2′ 3″ × 1′ 2′ × 1′ 0″	,,	
15	,, ,,	1′ 4″ × 1′ 2″ × 8″	,,	
16	Compact Sandstone . .	1′ 9″ × 1′ 6″ × 1′ 2″	Essendonbury farm; at entrance gate.	Very irregular in shape; taken from a neighbouring gravel pit.
17	Coarse Sandstone or Grit .	1′ 4″ × 11″ × 12″	Goose Green.	
18	Compact Sandstone . .	2′ 9″ × 1 9″ × 7″	Dalmond's farm; Mangrove Lane.	Taken out of a pond; from its regular thickness a doubtful specimen.
19	Herts Pudding-stone .	4′ 6″ × 3′ 3″ × 1′ 3″	Ibid., close to a fence adjoining farmhouse.	The finest of all the specimens.

CATALOGUE OF BOULDERS—*continued.*

o.	——	Dimensions	Where found	Remarks
0	Coarse Sandstone or Grit .	3′ 8″ × 1′ 11″ × 1′ 7″		
1	Compact Sandstone . .	1′ 3″ × 1′ 1″ × 8″	Jenningsbury farm.	Smooth faced; subangular; obtained from gravel pits.
22	Herts Pudding-stone .	3′ 0″ × 1′ 8″ × 2′ 0″	Stable-yard, 'Salisbury Arms,' Hoddesdon.	From the gravel pits; hard and tough.
23	Compact Sandstone . .	1′ 6″ × 1′ 3″ × 10″	From gravel pit, Roman road.	
24	Herts Pudding-stone .	11″ × 10″ × 7″	Ware Park Mill	
25	" "	2′ 7″ × 2′ 3″ × 1′ 4″	Ware.	From gravel pit, Park Road; found nearly at the surface.
26	Compact Sandstone . .	2′ 1″ × 1′ 5″ × 8″	Pepper Hill, Ware.	Such stones often found in this gravel pit; some of large dimensions; rather sharp angled, and smooth.
27	" "	1′ 4″ × 1 2″ × 10″	"	Smooth; subangular.
28	Coarse Sandstone or Grit .	2′ 8″ × 1′ 5″ × 1′ 3″	Amwell End, Ware.	Peculiarly ragged in shape, with rounded angles and indented.
29	" " "	2′ 2″ × 1′ 5″ × 1′	"	Flattish; subangular; appears as if split from a larger block.
30	Carboniferous Limestone ?	3″ × 1′ 7″ × 1′ 5″	Ware.	Taken out of water course; Angel Mead, Musley Lane.
31	Herts 'Pudding-stone' .	2′ 0″ × 2′ 0″ ×	Westmill Hill, Ware.	Smooth and subangular.
32	Coarse Sandstone or Grit .	2′ 0″ × 2′ 6″ × 1′ 4″	Opposite 'Rose and Crown,' Ware.	Smooth and subangular.
33	Compact Sandstone . .	1′ 10″ × 1′ 0″ × 1′	Hoddesdon.	Preserved in Bull Inn Yard.
34	" "	2′ 1″ × 1′ 4″ × 1′ 0″	Amwell.	Subangular; probably from gravel pit.
35	" "	1′ 7″ × 1′ 3″ × 7″	Amwell, Pepper Hill.	Rather sharp angled; from gravel pit.
36	" "	1′ 8″ × 1′ 6″ × 1′ 1″	Amwell.	Subangular; from adjoining gravel pit.
37	" "	1′ 6″ × 1′ 2″ × 1′ 3″	Ware.	From gravel pit.

Third Report of the Committee, consisting of Mr. R. ETHERIDGE, Dr. H. WOODWARD, *and* Professor T. RUPERT JONES (*Secretary*), *on the Fossil Phyllopoda of the Palæozoic Rocks.*

§ I. SUPPLEMENTARY.—1. Professor C. Lapworth enables us to make the following corrections in the Second Report, 'Brit. Assoc. Report for 1884':—(1) The horizon of *Discinocaris gigas* (p. 80) is the 'Llandovery, in the Birkhill Shales.' (2) '*D. Browniana* (p. 78) also comes from the

Llandovery stage;[1] in fact, all the British Silurian forms of *Discinocaris* come from the same general horizon—the Llandovery (Birkhill series).' (3) '*Aptychopsis Wilsoni* (p. 89) occurs in the Wenlock stage (Riccarton Beds).' (4) '*Aptychopsis glabra* (pp. 91 and 92) is from the Middle Silurian Buckholm Beds of the Gala Group, Meigle, Galashiels, Selkirkshire. Its horizon in Tipperary may be Middle, rather than Lower, Silurian.' (5) '*Peltocaris aptychoides* (p. 93) from Duff-Kinnel belongs to the Llandovery stage (Birkhill Shales).' (6) '*Peltocaris* sp. (p. 94) occurs at Whitehope (not Wasthope) Burn, in the Birkhill series.' With the exception of *Peltocaris Harknessi*, all the forms of *Aptychopsis* and *Peltocaris* known to Professor Lapworth are of either Llandovery or Lower-Wenlock age.

2. *Caryocaris Marrii.* Another specimen has been observed in the British Museum, No. '42162.' See First Report, 'Brit. Assoc. Report for 1883,' p. 222.

3. *Lingulocaris siliquiformis.* First Report, 1883, p. 223, lines 13 and 14 from the bottom, *read* Schistose Bala rock, and collected by J. P., March 14, 1868. A fragment (from Garth) has been also noted in the Museum of Practical Geology, IV $\frac{2}{4}$, 'Catal. Cambr. Sil. Foss. M.P.G.' 1878, p. 15. We find also another specimen of *Lingulocaris lingulæcomes* (from Garth) in the British Museum, No. '48001.' See First Report, 1883, p. 223.

4. A form near *Solenocaris*, Meek, is in the Mus. Pract. Geol. X $\frac{1}{27}$, 'Catal. Cambr. Sil. Foss.' 1878, p. 142. From Freshwater-East, Pembrokeshire, north side; Ludlow Beds.

5. *Orthotonella? Faberi*, E. O. Ulrich, 'Journ. Cincinnati Soc. Nat. Hist.' vol. v. (1882?), p. 117, pl. 5, figs. 7, *7a*, *7b*, has a Phyllopodiform aspect, somewhat like that of Meek's *Solenocaris*, and we therefore asked Mr. Ulrich to look at it again; and he obligingly replies that it may possibly be one of these bivalved crustaceans.

6. *Solenocaris solenoides*, Young, 1869, alluded to in our First Report, 'Brit. Assoc. Report' for 1883, pp. 217 and 223, as a conchiferoidal Phyllopod, has been further studied, good specimens having been kindly supplied by Mrs. Gray, of Edinburgh. It is carefully described and figured in the 'Geol. Mag.' for August 1885, p. 356, pl. IX, fig. 11; and, proving not to be a Phyllopod, is referred to *Helminthochiton* as *H. solenoides* (Young); and another species of the same genus has been found by Mrs. Gray at Thraive, near Girvan, and has been described with the former as *H. Grayiæ*, H. Woodward, figs. 7–10. The little 'oblong, obliquely ridged, and concentrically marked' bodies are moieties of the dorsal plates of *Helminthochiton*. A nearly perfect series of whole plates found by Mrs. Gray at Thraive, near Girvan, is figured and described in Dr. Woodward's memoir.

7. With reference to *Goniatites* having *Aptychi* or *Anaptychi*, and as to some of the so-called Phyllopodous shields being really such parts of *Goniatites*,[2] we have to state that, in confirmation of Herr Kayser's discovery of a '*Spathiocaris*' in the body-chamber of a Devonian Goniatite, we have now seen some similar examples from Bicken; and that we believe some of the so-called Phyllopodous shields which come from

[1] We notice that in the *Quart. Journ. Geol. Soc.* xxxvi. 1880, p. 617, Mr. Marr states that Herr Dusl has three specimens of *Discinocaris Browniana* from the strata of 'Colonie Haidinger,' in Bohemia (= Stage E e 1, according to Mr. Marr).

[2] See the Second Report, 1884, p. 76.

Goniatitiferous Devonian strata will have to be referred to *Goniatites*. Thus we must look with some doubt on the following Devonian forms :—

Discinocaris dubia (Roemer)	See Second Report, 1884, p. 79.
„ *lata* (Woodward)	„ „ „
„ *congener* (Clarke)	„ „ p. 80.
Spathiocaris Emersonii, Clarke	„ „ „
„ *ungulina*, Clarke	„ „ p. 81.
Pholadocaris Leeii, Woodward „ *sp.*	„ „ p. 82.
Ellipsocaris Dewalquei, Woodward „ *sp.*	„ „ p. 83.
Cardiocaris Roemeri, Woodward „ *bipartita*, Woodward „ *Veneris*, Woodward „ *Koeneni* (Clarke)	„ „ p. 84.
Dipterocaris pes-cervæ, Clarke „ *retusta* (D'Arch. and De Vern.) „ *procne*, Clarke	„ „ p. 85.

These, then, require further investigation ; but as numerous undoubted Phyllopoda, having structural features allied to those of the foregoing genera and species, occur in the Silurian strata that do not yield Goniatites, and as some even of the genera enumerated above are not always associated with Goniatites, there is no reason why members of the group should not occur even in Goniatitiferous strata. Thus some of the foregoing species may have no relationship with the Cephalopods among which they have been buried, but were lineal descendants of Silurian forms.

In his paper in the 'Neues Jahrbuch,' &c., 1884, Band i. p. 275, &c., 'On the Phyllopod-nature of *Spathiocaris*, *Aptychopsis*, and similar bodies,' met with in strata of Silurian, Devonian, and Carboniferous ages in Europe and North America, and described by M'Coy, Salter, Barrande, Meek, Hall, Clarke, ourselves, and others, after an elaborate criticism of the subject, Herr W. Dames concludes :—

1.—That some of the bodies in question are the *Aptychi* of *Goniatites*.

2.—That for others, this explanation is, according to our present knowledge, inadmissible.

3.—That the last are, however, in no case Phyllopods.

1.—As intimated above, we accept the first conclusion. The British Museum lately obtained several specimens of these *Aptychus*-like bodies,[1] from the black limestone of Bicken; and Mr. Robert Etheridge, jun., discovered among them a specimen of a small *Goniatites intumescens* with an imperfect *Aptychus in situ* in its mouth-aperture. This *Aptychus* seems to agree most nearly in form with the so-called '*Cardiocaris lata*,' from Budesheim in the Eifel,[2] also observed by Mr. J. M. Clarke at Bicken.[3] The other specimens of *Aptychus*-like bodies, not *in situ*, but from the same black Devonian limestone, agree *very closely* with Mr. Clarke's *Spathiocaris Koeneni*,[4] also from Bicken.

[1] We have also seen a specimen of *Aptychus* sent to Mr. John Edward Lee, of Torquay, by Professor Ferd. Roemer, of Breslau, and labelled '*Aptychopsis*, sp.= operculum of *Goniatites intumescens*, Upper Devonian, Bicken, near Herborn, Nassau,' in Dr. Roemer's own handwriting. Some of these specimens have been figured in the 'Geol. Mag.' dec. 3, vol. ii. pl. ix. figs. 1–6, in illustration of a paper (pp. 345–352) treating of this subject in full, and of the relationship of the fossil Phyllopods under notice to Nebalia.

[2] See 'Geol. Mag.' 1882, dec. 2, vol. ix. p. 388, pl. ix. fig. 13.

[3] 'Neues Jahrb.' &c. 1884, vol. i. p. 181, pl. iv. fig. 2.

[4] *Ibid.* fig. 1.

2.—Even after all those forms of supposed Phyllopod shields which occur in beds in which *Goniatites* have been found shall have been re-examined, we feel convinced, with Herr Dames, 'that for others, this explanation is, according to our present knowledge, inadmissible.'

The First and Second Reports drawn up by ourselves [1] on the PHYLLOPODA fully confirm Herr Dames' own conclusion that *all* the simple disc-like or bivalved shields met with in the older rocks cannot be regarded as the opercula of Cephalopods. There are indeed many special characters about these Palæozoic Phyllopod shields that will require to be carefully examined before they can all be referred to *Goniatites*. We would draw attention to the varied form of the notch; the absence in some, and the presence in others, of the dorsal suture; the presence in different genera of the rostral portion of the shield in the circular and oval forms, and the possible existence in some of a hinder trigonal shield-piece (*Pholadocaris*, *Dipterocaris*); the shape of the shield itself; the ornamentation; and, lastly, the substance composing it. Usually it is possible to discern the difference in character between Crustacean and Molluscan structures, as also between these and obscure Ichthyic fragments.

We note the following assertion in reference to the body-rings of *Discinocaris*: 'Even if the structures observed are really body-rings, no stronger proof against their phyllopod nature could be brought forward; for the body-rings, as well as all the other parts of the Phyllopod (except the shell), are *too tender and fragile* to remain recognizable in beds of such great age.' [2] (Dames, *op. cit.*)

In the presence of the long array of Insect-remains, of the most delicate and fragile characters, discovered in the Devonian and Carboniferous formations of North America, France, England, and elsewhere, this argument against the possibility of delicate organisms being preserved falls to the ground; whilst the relative thickness and durability of the calcareous or chitinous covering of the body-segments in these ancient Crustacea afford no proof for or against their Phyllopod nature, any more than does their relatively greater size when contrasted with existing Entomostraca. Moreover body-rings of *Ceratiocaris* are by no means rare in some Silurian strata.

3.—In the third conclusion, 'that even those forms which cannot be referred to *Aptychi* of Cephalopods, are in no case the shields of Phyllopods,' Herr Dames is simply stating a matter of opinion; for of their exact nature and true zoological position Claus himself (to whom he seems to refer) is not at all positive, whilst Dames admits that he has not examined the original specimens.

We have long held the opinion that the expanded disc-like shields, such as *Peltocaris*, *Discinocaris*, *Aptychopsis*, and some others, were pro-

[1] Also 'Geol. Mag.' 1883, dec. 2. vol. x. pp. 461–464; and 1884, dec. 3, vol. i. pp. 348–356.

[2] Professor A. von Koenen, replying to Herr Dames, on behalf of Mr. J. M. Clarke, very justly observes, 'I cannot see that this at all meets the argument, since the relative age of strata is of little influence on the preservation of fossils; on the other hand, there are plenty of examples in which fossil animals have been furnished with hard, horny, and even calcareous parts which are wanting in their nearest recent analogues. I will only recall here *Aptychus* and *Anaptychus*' ('N. Jahrbuch,' &c. 1884, Bd. ii. p. 45). The recent *Nautilus* has a fleshy hood; the fossil Ammonite had usually a hard calcareous *operculum*, but in some Liassic forms the operculum was *horny*.

bably related ancestrally to the larval or adult forms of Phyllopods like *Apus*, *Lepidurus*, &c. whilst the relationship between the living *Nebalia* and the numerous genera of Palæozoic Pod-shrimps does not necessarily preclude us from considering these forms as still belonging to the ENTOMOSTRACA, although placed in Packard's order PHYLLOCARIDA.

As to the question of ornamentation, upon which Herr Dames insists so strongly, the concentric striæ, marking lines of growth, appear to correspond most closely in character and origin with the similar decoration observable on the valves of *Estheria*, *Limnadia*, &c. so that their absence upon the carapaces of *Apus* and *Nebalia* does not necessarily prove that shields so ornamented cannot be deemed to belong to Crustacea or even to the PHYLLOPODA; whilst many of the carapaces of the fossil genera, e.g. *Dithyrocaris*, *Ceratiocaris*, &c. have either concentric or anastomosing striæ covering the entire surface of their carapaces; yet Herr Dames has evidently no doubt that these forms are related to *Nebalia*, which has a smooth carapace destitute of ornamentation.

He reminds us that Claus and Gerstaeker are of opinion that *Nebalia* is not a *Phyllopod*. Because *Nebalia* during its embryonal life (whilst still in the egg) passes through the 'Nauplius-' and 'Zoëa-stages,' which in Decapods occur partly in the free state, it has been regarded by some as a 'Phyllopodiform-Decapod.' The *potentiality* of a form to attain to a higher existence seems to be here mistaken for *actuality*. Since it never attains a higher development as an adult than that of a Phyllopod, and has no retrograde metamorphosis, may we not with as equal reason regard *Nebalia* as a highly-organised *Phyllopod*, as to assert that it is a Decapod arrested at the Phyllopod stage?

All who have studied the PHYLLOPODA have been struck by the peculiar points of special interest to be observed in *Nebalia*.[1]

Milne-Edwards, in his 'Histoire Naturelle des Crustacés' (1840), places *Nebalia* in the family *Apusidæ* among the Phyllopods; at the same time he remarks, 'The *Nebaliæ* are very singular little crustaceans, which, by reason of their stalked eyes [2] and their carapace, approach the PODOPHTHALMIA; they do not, however, possess branchiæ, properly so called, but they respire by the aid of their thoracic feet, which are developed into membranaceous and foliaceous appendages. They resemble in many respects, and establish a passage between *Mysis* and *Apus*.'

Baird (1850) founded the family *Nebaliadæ*, and regarded *Nebalia* as a Phyllopod.

Prof. J. D. Dana (1853), in his great work on the Crustacea, retained the family name (*Nebaliadæ*), which he placed in the PHYLLOPODA.

Metschnikoff in 1865 published an abstract of his account of the development of *Nebalia Geoffroyi*, and in 1868 the full essay in the Russian language. Fritz Müller, in his 'Für Darwin,' states that Metschnikoff has observed 'that *Nebalia*, during its embryonal life, passes through the Nauplius- and Zoëa-stages, which in the Decapoda occur

[1] For a very full account of *Nebalia* see the twelfth Annual Report of the United States Geological Survey, Part I. Geology, Palæontology, and Zoology, 8vo, 1883 (Washington), 'A Monograph of the Phyllopod Crustacea of North America, with remarks on the order *Phyllocarida*,' by A. S. Packard, jun., pp. 295–592, and plates i.–xxxix. See also the *American Naturalist* for October, November, and December, 1882, vol. xvi. pp. 785, 861, 945.

[2] Pedunculated eyes are also present in *Branchipus* and *Artemia*, so that the stalked eyes of *Nebalia* can scarcely be regarded as an essentially distinctive character.

partly (in *Penæus*) in the free state.' 'Therefore,' he adds, 'I regard *Nebalia* as a Phyllopodiform Decapod.'

In 1872 Claus gave an account, with excellent figures, of the external anatomy of *Nebalia Geoffroyi*, and in 1876 he described the internal anatomy.

In 1875 in the account of the Atlantic Crustacea of the 'Challenger' Expedition, Willemoes-Suhm placed the *Nebaliadæ* among the *Schizopoda*.

In 1879 Dr. A. S. Packard, jun., in the 'American Naturalist,' vol. xiii. p. 128, proposed that *Nebalia* and its fossil allies should be placed in a new order, which he proposed to name the PHYLLOCARIDA. Dr. Packard writes:—

'The *Nebaliadæ*, represented by the existing genus *Nebalia*, have generally been considered to form a family of Phyllopod Crustacea. Metschnikoff, who studied the embryology of *Nebalia*, considered it to be a "Phyllopodiform Decapod." Besides the resemblance to the Decapods, there is also a combination of Copepod and Phyllopod characteristics. The type is an instance of a generalised one, and is of high antiquity, having been ushered in during the earliest Silurian period, when there were (when we regard the relative size of most Crustacea, and especially of living *Nebaliæ*) gigantic forms. Such was *Dithyrocaris*, which must have been over a foot long, the carapace being seven inches long. The modern *Nebalia* is small, about half an inch in length, with the body compressed, the carapace bivalved as in *Limnadia*, one of the genuine Phyllopods. There is a large rostrum overhanging the head; stalked eyes; and, besides two pairs of antennæ and mouth-parts, eight pairs of leaf-like, short, respiratory feet, which are succeeded by swimming-feet. There is no metamorphosis, development being direct.

'Of the fossil forms, *Hymenocaris* was regarded by Salter as "the more generalised type." The genera *Peltocaris* and *Discinocaris* characterise the Lower-Silurian period, *Ceratiocaris* the Upper, *Dictyocaris* the Upper-Silurian and the lowest Devonian strata, *Dithyrocaris* and *Argas* the Carboniferous period. Our existing north-eastern species is *Nebalia bipes* (Fabricius), which occurs from Maine to Greenland.

'The Nebaliads were the forerunners of the DECAPODA, and form, we believe, the type of a distinct order of Crustacea, for which the name PHYLLOCARIDA is proposed.'

The order PHYLLOCARIDA has been thus defined:—

PHYLLOCARIDA, Packard (1879). Body long, with five cephalic, eight thoracic, and eight abdominal segments, with a thin or chitinous skin; generally covered with a bivalved shell having a movable rostrum. Eyes pedunculated and faceted. Upon the under side of the head are two pairs of antennæ; the mandibles and two pairs of maxillæ furnished with palpi. The body-segments are compressed, they support eight pairs of large Phyllopodiform thoracic feet. The abdomen composed of eight large segments,[1] provided with six pairs of simple swimming-feet fringed with setæ, of which the four anterior pairs are the largest, and the two posterior pairs are very small. The abdomen terminates in setaceous filaments, or in a telson divided into three or more parts. (Zittel, 'Handbuch der Paläontologie,' Munich, 1885.)

[1] The abdomen is nine-jointed, unless the last somite be considered as the telson (it is post-anal). It is a long and slender segment, and bears two very long narrow setigerous cercopods, closely resembling those of the Copepoda.

In 1880 Professor Claus, 'Lehrbuch der Zoologie,' writes, 'This remarkable form (*Nebalia*) was for a long time regarded as a Phyllopod, and in many of its characters it represents a connecting link between the PHYLLOPODA and the MALACOSTRACA. The structure and segmentation of the head and thorax resembles that of the Malacostraca, but the terminal region of the abdomen does not present the special form of a caudal plate or telson. In *Nebalia* we probably have to do with an offshoot of the Phyllopod-like ancestors of the MALACOSTRACA, which has persisted to the present time.' He adds, '*Nebalia* is best placed in a special group LEPTOSTRACA, between the ENTOMOSTRACA and MALACOSTRACA. The Palæozoic genera *Hymenocaris*, *Peltocaris*, &c. would have to be placed in such a group.'[1]

'It is,' writes Professor Claus, 'in the highest degree probable that all these' (Palæozoic PHYLLOCARIDA) 'are not true Phyllopods, but have belonged to a type of Crustacea, of which now there are no living representatives, but which, taking their origin from forms allied to the lower types of Entomostraca, have prepared the way for the Malacostracan type. Such a connecting link, which has served to the present day, we evidently find in the genus *Nebalia*.'[2]

In his 'Handbuch der Paläontologie,' Munich, 1885, Professor Dr. K. A. Zittel adopts Packard's order PHYLLOCARIDA, but places it under the MALACOSTRACA, and between the EDRIOPHTHALMIA and the MEROSTOMATA.

In his article on the Palæozoic allies of *Nebalia*, Dr. A. S. Packard, jun., thus sums up the PHYLLOCARIDA: 'From our total lack of any knowledge of the nature of the limbs of the fossil PHYLLOCARIDA, we have to be guided solely by analogy, often an uncertain and delusive guide. But in the absence of any evidence to the contrary, there is every reason to suppose that the appendages of the head, thorax, and abdomen were on the type of *Nebalia*, since there is such a close correspondence in the form of the carapace, rostrum, and abdomen. But whatever may be the differences between the fossil forms represented by *Ceratiocaris*, &c., they certainly seem to approach *Nebalia* much nearer than any other known type of Crustacea; they do not belong to the DECAPODA; they present a vague and general resemblance to the zoëa or larva of the Decapods, but no zoëa has a telson, though one is developed in a postzoëal stage; they do not belong to any other Malacostracous type, nor do they belong to any existing Entomostracous type, using those terms in the old sense. No naturalist or palæontologist has referred them with certainty to the Decapods or to any other Crustacean type than the Phyllopods. To this type (in the opinion of Metschnikoff and Claus, who have studied them most closely) they certainly do not belong, and thus reasoning by exclusion they either belong to the group of which *Nebalia* is a type, or they are members of a lost, extinct group. The natural conclusion, in the light of our present knowledge, is that they are members of the group represented by the existing *Nebalia*.' 'The differential characters separating them from the Decapods or any other Malacostracous type are—

1. The loosely-attached carapace, the two halves connected by an adductor muscle.

[1] Claus, translated by Sedgwick (Cambridge), p. 448 (footnote), 8vo, 1884. The *Leptostraca* (Claus) are thus defined: 'Crustacea with thin, folded carapaces, mostly bivalved, under which all the thoracic rings remain as free segments' (Zittel, 'Handb. Paläontol.' 1885, p. 655).

[2] Claus in Siebold and Kölliker's 'Zeitschrift,' xxii. 1872, p. 329.

2. The movable rostrum, loosely attached to the carapace.

3. The very long and large mandibular palpus; the long slender appendage of the first maxilla, and the very long bi-ramous maxillæ.

4. The absence of any maxillipeds.

5. The eight pairs of pseudo-phyllopod thoracic feet, not adapted for walking.

[To these we would add—5*a*. The "telson" long and slender, with two long narrow setigerous cercopods as in the Copepoda.]

6. The animal swimming on its back.

7. No zoëa-formed larva.

The characters which separate it from the Phyllopods are—

1. Carapace not hinged; a rostrum present.

2. Two pairs of well-developed long and large multiarticulate antennæ; the hinder pair, in the male, longer than the first pair.

3. The thorax and its appendages clearly differentiated from the abdomen.'[1]

Nebalia has been so long regarded as the surviving representative of those more ancient and gigantic forms of PHYLLOCARIDA, which existed in such numbers in the Cambrian and Silurian Seas, and became nearly extinct towards the close of the Carboniferous epoch, that any decision affecting its zoological position cannot be a matter of indifference to the palæontologist.

But after studying its larval development and adult structural modifications, we arrive at the fact that *Nebalia* is a more generalised type than is ordinarily to be found at the present day, 'combining Copepod, Phyllopod, and Decapod-like features, with other more fundamental characters of its own' (Packard), which preclude us from regarding it as a true Malacostracan, and, although ancestrally related to that order, it nevertheless does not attain, in our opinion, to the Malacostracan grade of development.[2] They should therefore be arranged in a distinct order (the PHYLLOCARIDA) between the ENTOMOSTRACA and the MALACOSTRACA, as suggested by Claus. But if it is undesirable to have such an outstanding group, then we contend that the balance turns in favour of retaining it in the former division, if not in the order PHYLLOPODA as heretofore.

Thus we conclude:—

1. Some of the supposed 'Phyllopod shields' from Budesheim and Bicken are probably *Aptychi* of *Goniatites*.

2. That for others of the Palæozoic Phyllopods, described in the Reports of 1883–84, this explanation is inadmissible.

3. That those which cannot be referred to *Aptychi* are still, in all probability, Phyllopods.

4. That the *Nebalia*-like forms, now placed in the order PHYLLOCARIDA, are *certainly not Decapods*. And even if they may not with propriety be retained any longer in the old order PHYLLOPODA (of which we are by no means sure), yet they may more correctly be placed beside

[1] *American Naturalist*, 1882, vol. xvi. p. 951; and *Monograph N. Amer. Phyllopods*, &c. 1883, pp. 447–8.

[2] Dr. Packard writes, 'There is little to indicate that the Schizopods (*Mysis*, &c.) have descended from a *Nebalia*-like form, but rather from some accelerated zoëa form; while the Phyllocarida *have had no Decapod-blood in them*, so to say, but have descended by a separate line from Copepod-like ancestors, and culminated, and even began to disappear, before any Malacostraca, at least in any numbers, appeared.' *American Naturalist*, 1882, vol. xvi. p. 873.

them in the Entomostraca than in the Malacostraca, seeing they have not actually attained to the grade of the latter, but only approached to its larval development; whilst to the former the adult *Nebalia* has many very strong points of affinity.

§ II. Ceratiocaridæ.—Dr. Packard's observations on the structure of the Phyllopods, and his studies of the comparative anatomy of living and fossil forms, supply the palæontologist with sound reasoning in referring the *Phyllocarida* to the Nebaliad type as a centre for a great group of obscure fossil forms, and as a starting-point for the Decapoda. We have referred to his views in some detail in the foregoing pages.

Order. Phyllocarida, Packard.

Genus Ceratiocaris, M'Coy.

The generic characters of *Ceratiocaris* have been described by M'Coy, Salter, H. Woodward, and Barrande in their several works and memoirs referred to in the sequel. James Hall, R. P. Whitfield, A. S. Packard, J. M. Clarke, Fr. Schmidt, C. E. Beecher, O. Novák, and others have added much information, general and special, on this and allied genera. The appended synonymy of the genus supplies full references to published notices on *Ceratiocaris* and some of its allies.

We offer the following diagnosis of *Ceratiocaris*. Carapace bivalved, probably with membranous attachment, no distinct hinge-joints being observable; valves subovate, semiovate, subquadrate, or trapezoidal; contracted in front with the end sharp or rounded above the median line of the valve; more or less truncate behind. Rostrum elliptical in shape, of a single lanceolate piece, chevron-marked. Antennæ (?) obscure. Teeth often apparent. Body many-jointed, with fourteen or more segments, of which 4–7 extend beyond the carapace, ornamented with delicate raised lines. Some or all of these segments bore small lamelliform branchial appendages.[1] Last segment, the longest, supporting three caudal spines, namely: (1), a strong tapering telson (style), thick at the top or proximal end, with its three-knobbed articulating surface (resembling that in the telson of *Limulus*), pointed at the other, and more or less spinose, as shown by the bases of little prickles; and (2), two shorter, simpler, lateral appendages (stylets). The surface of the valves has a lineate ornament, and the ventral margin has a thin raised rim.

Respecting the abdominal appendages which Mr. R. Etheridge, jun., described in Appendix III. of the 'Memoirs Geol. Survey Scotland: Explanation of Sheet 23,' 1873, p. 93, he there remarks:—' A further advance in the structure of this genus of Crustacea has been satisfactorily established from specimens obtained at Lesmahagow by the Collector of the Geological Survey, viz. the presence of respiratory locomotive appendages. On a slab of thin-bedded shale are exposed the abdominal segments, telson, and caudal appendages of a *Ceratiocaris*. From the ventral margin of the terminal segment, to which are attached the telson-spines (*Leptocheles*, M'Coy), proceeds a broad, paddle-shaped, membranous (?) expansion, presenting a strong marginal outline, with a transversely striated surface. This is followed by another similar appendage, proceeding in the same manner from the penultimate segment (somite). Along the dorsal margin there is seen what appears to be the

[1] See the 'Sixth Report on Fossil Crustacea,' *Brit. Assoc. Report* for 1872, p. 323.

remains of one of the corresponding "foot-gills," on the other side, bent back upon itself, and thus thrust out of place. The free ends of these foot-gills are attenuated to more or less rounded points. They do not show any evidence of having possessed a marginal fringe. The discovery of these branchial locomotive appendages tends to ally *Ceratiocaris* still further with the genus *Nebalia*. See "Geol. Mag." vol. ix. p. 564. *Loc.*: No. 292 (Linburn or Linn Burn, about two miles N. of Muirkirk, Lanarkshire). In thin-bedded shale (Upper Ludlow). Collected by A. Macconochie.' Mr. R. Etheridge, jun., again alludes to this interesting subject in the 'Annals and Mag. Nat. Hist.' ser. 4, vol. xiv. 1874, p. 9.

Ceratiocaris, M'Coy, 1849.

1839. *Onchus*, Agassiz (in part). In Murchison's 'Silurian System,' p. 607.
1848. *Onchus*, Phillips (in part). 'Mem. Geol. Surv.' vol. ii. part 1, p. 226.
1849. *Pterygotus*, M'Coy. 'Ann. Mag. N. H.' ser. 2, vol. iv. p. 394.
1849. *Ceratiocaris*, M'Coy. 'Ann. Mag. N. H.' ser. 2, vol. iv. p. 412.
1851. *Pterygotus*, M'Coy. 'Brit. Palæoz. Fossils,' fasc. 1, p. 175.
1851. *Leptocheles*, M'Coy. 'Brit. Palæoz. Foss.' fasc. 1, p. 176.
1851. *Ceratiocaris*, M'Coy. 'Brit. Palæoz. Foss.' fasc. 1, p. 136.
1851. *Pterygotus (Leptocheles)*, Bronn. 'Lethæa Geognost.' vol. i. part 1, p. 40.
1852. *Onchus*, James Hall. 'Geol. Surv. New York, Palæontology,' vol. ii. p. 320.
1852. *Ceratiocaris*, Bronn. 'Leth. Geogn.' vol. i. part 2, p. 539.
1853. *Dithyrocaris*, Geinitz. 'Verst. Grauwack. Sachsen,' Heft II. p. 23.
1853. *Leptocheles*, M'Coy. 'Quart. Journ. Geol. Soc.' vol. ix. p. 13.
1853. *Ceratiocaris (Leptocheles)*, Barrande. 'Neues Jahrb. für Min.' &c. 1853, Heft III. p. 342.
1853. *Dithyrocaris?*, D. Sharpe. 'Quart. Journ. Geol. Soc.' vol. ix. p. 158.
1854. *Ceratiocaris et Leptocheles*, Murchison. 'Siluria,' 1st edit. p. 236.
1854. *Ceratiocaris*, Morris. 'Catal. Brit. Foss.' 2nd edit. p. 102.
1856. *Ceratiocaris*, Salter. 'Quart. Journ. Geol. Soc.' vol. xii. p. 33.
1859. *Ceratiocaris*, J. Hall. 'Geol. Surv. New York, Palæontology,' vol. iii. p. 420.
1859. *Ceratiocaris*, Salter. In Murchison's 'Siluria,' 2nd edit. (3rd including 'Sil. Syst.'), pp. 262, 538.
1860. *Ceratiocaris*, Salter. 'Ann. Mag. Nat. Hist.' ser. 3, vol. v. p. 158.
1863. *Ceratiocaris*, James Hall. 'Sixteenth Ann. Rep. of the Regents,' &c. p. 72, pl. 1.
1865. *Ceratiocaris*, H. Woodward and J. W. Salter. Cat. and Chart of Foss. Crustacea.
1865. *Ceratiocaris*, H. Woodward. 'Geol. Mag.' vol. ii. p. 401.
1865. *Ceratiocaris*, Huxley and Etheridge. 'Catal. Foss. Mus. Pract. Geol.' p. 79.
1866. *Ceratiocaris*, H. Woodward. 'Geol. Mag.' vol. iii. p. 203.
1866. *Ceratiocaris*, Salter. 'Mem. Geol. Surv.' vol. iii. p. 294.
1867. *Ceratiocaris*, Salter. In Murchison's 'Siluria,' 3rd edit. (4th including 'Sil. Syst.') pp. 236 and 516.
1868. *Ceratiocaris*, Bigsby. 'Thesaur. Silur.' p. 73.
1871. *Ceratiocaris*, H. Woodward. 'Geol. Mag.' vol. viii. p. 104.
1872. *Ceratiocaris*, H. Woodward. 'Geol. Mag.' vol. ix. p. 564; and 'Report Brit. Assoc.' for 1872, p. 323.
1872. *Ceratiocaris*, Barrande. 'Syst. Sil. Bohême,' vol. i. Suppl. p. 437.
1873. *Ceratiocaris*, Salter. 'Catal. Cambr. Sil. Foss. Woodw. Mus.' p. 177.
1873. *Ceratiocaris*, R. Etheridge, jun. 'Mem. Geol. Surv. Scotl. Expl. Map 23,' p. 93.
1873. *Ceratiocaris*, Marschall. Nomenclator Zoologicus,' p. 404.
1874. *Ceratiocaris*, R. Etheridge, jun. 'Ann. Mag. N. H.' ser. 4, vol. xiv. p. 9.
1876. *Ceratiocaris*, Ferd. Roemer. 'Lethæa geognost.' Theil i. 'Leth. palæozoica,' Expl. pl. 19.
1877. *Ceratiocaris*, H. Woodward. 'Catal. Brit. Foss. Crust.' p. 70.
1877. *Ceratiocaris*, Miller. 'Catal. Palæoz. Foss. America,' p. 213.
1878. *Ceratiocaris*, Huxley & Etheridge. 'Catal. Foss. Mus. Pract. Geol.' p. 84.
1878. *Ceratiocaris*, Bigsby. 'Thes. Devonico-Carbonif.' pp. 26, 246, and 247.
1878. *Ceratiocaris*, Young. 'Proceed. R. Phys. Soc. Edinb.' vol. iv. p. 168.
1880. *Ceratiocaris*, Whitfield. 'Amer. Journ. Sci.' ser. 3, vol. xix. p. 35.

1882. *Ceratiocaris*, B. N. Peach. 'Trans. R. Soc. Edinb.' vol. xxx. part 1, p. 73.
1883. *Ceratiocaris*, A. S. Packard, jun. 'Monogr. North-Amer. Phyllop. Crust.'; 'Twelfth Ann. Rep. U. S. Geol. and Geograph. Survey,' p. 450.
1884. *Ceratiocaris*, C. E. Beecher. 'Ceratiocaridæ Upper-Devon. Measures'; 'Second Geol. Surv. Penns. P.P.P.' p. 2.
1885. *Ceratiocaris*, O. Novák. 'Sitzungsb. k. böhm. Gesellsch. Wissensch.'
1883. *Ceratiocaris*, H. W. and T. R. J. 'Report Brit. Assoc.' for 1883, p. 217.
1884. *Ceratiocaris*, T. R. J. and H. W. 'Geol. Mag.' Dec. 3, vol. i. p. 396.

A. *British Species.*

1. CERATIOCARIS MURCHISONI (Agassiz), and its variety LEPTODACTYLUS (M'Coy).

Some imperfect caudal appendages or spines (telson or style, and lateral spines or stylets), from the Uppermost Ludlow strata, near Ludlow, were figured in Murchison's 'Silurian System,' in 1839, as fish-defences. These were recognised by Prof. F. M'Coy in 1853 as being very similar to some analogous fossils, referred by him at first (in 1849) to a slender-clawed kind of *Pterygotus* from the Lower Ludlow, at Leintwardine, near Ludlow, which he separated from that genus as *Leptocheles leptodactylus.* M'Coy suggested that Murchison's fossil should be known as *L. Murchisoni.*[1]

In each case we have only caudal spines to deal with; but M'Coy's specimens ('Brit. Pal. Foss.' pl. 1 E, figs. 7, 7*a*, 7*b*) are much more slender than Murchison's ('Sil. Syst.' pl. 4, figs. 10 and 64, and 'Siluria,' pl. 19, figs. 1, 2), and less strongly ribbed; and therein they seem at first sight to have specific differences.

Several good examples of more or less perfect sets of the three caudal spines corresponding in size, strength, and ribbing with Murchison's fossils have been met with. These show evidence of lines of prickles (by the presence of little pits, representing their bases, along one or more lines); and on close examination the engravings in the 'Sil. Syst.' and 'Siluria' (the specimens have been lost) show some slight indications of this spinose ornament. This is not visible, however, in M'Coy's figures or specimens (Cambridge Museum, *a*/923, *a*/924). Of these latter, more delicate, caudal appendages, very few other examples occur.

In the collocation of these caudal appendages with their respective *carapaces* we have some doubt and difficulty.

We have not found a carapace directly associated with any complete spines of either the *Murchisoni* or *leptodactylus* type except in the case of a very small specimen (M. P. G. x $\frac{1}{4}$), which appears to have the caudal appendages of *C. Murchisoni* and the carapace of Salter's '*leptodactylus.*' With regard to both, however, the late Mr. J. W. Salter satisfied himself that he knew their special carapaces, for he described them at p. 157 of the 'Ann. Mag. Nat. Hist.' for March 1860: where also he refers both species to the *Ceratiocaris* of M'Coy. Judging from his Latin diagnoses, he allocates to the former—'a cephalothorax (carapace) two inches long, oblong, convex, ornamented with interrupted, nearly-straight, wide-apart lines. The caudal appendages long, sub-cylindrical; the central spine

[1] Prof. M'Coy's observations are as follows:—'. . . As before mentioned, figs. 9, 10, and 11 [*Sil. Syst.* pl. 4; omit figs. 9 and 11], representing the so-called *Onchus Murchisoni*, Ag., are almost identical in form, size, sculpturing, and all other characters (as far as they are represented in these drawings), with the distinctly didactyle pincers which I have figured (*Brit. Pal. Foss.* pl. E, fig. 7) from Leintwardine, under the name *Lept. leptodactylus*. . . . If this approximation prove correct, the fossil should in future be called *Leptocheles Murchisoni* (Ag. sp.).'—*Q. J. G. S.* vol. ix. 1853, p. 13.

(telson) strong, bulbous at its base, and with a strong dorsal rib; the side spines long. All ribbed. The whole animal medium-sized. Specimens possessed by the geologists at Ludlow and by the Museum of Practical Geology.' The carapace described here does not agree with any that we can associate with the caudal spines intended. Nor do we find at Ludlow exactly the kind of carapace required.

To *C. leptodactylus* Mr. Salter apportioned—'a cephalothorax long, triangular, acute in front, broad and rounded behind. Free abdominal segments 7–8 in number, subquadrate, deeply impressed at the sides. Caudal appendages long, striate; the central spine (telson) scarcely thicker than the long lateral spines. Surface of the head (carapace) smooth, or marked with only very short sparse lines. Abdominal segments strongly striate. The whole animal elongate and more than a foot long.' One particular specimen in the Mus. Pract. Geol. is referred to by Mr. Salter at p. 158. We are at a loss here also in fitting the indicated (slender) appendages to the carapace described. We have examined this and other good specimens, labelled *C. leptodactylus* by Mr. Salter or at his direction, in which the *carapace* agrees with his description. One carapace is of large size, nearly perfect, about 125 mm. (5 inches) long, by 55 mm. at greatest height; M. P. G. x $\frac{1}{5}$, 'Catal. Cambr. Sil. Foss.' 1878, p. 142. A specimen nearly perfect, M. P. G. x $\frac{1}{7}$ ('Catal.' 1878, p. 142), 60 mm. long by 28 mm., gives no certain indication of the length of its telson and its two stylets, for they are crushed off short. The abdomen exposed is about 50 mm. In specimen D of the Ludlow Museum, which has the proximal portion only of the caudal spines preserved, and in specimen B, with the appendages also broken off short, the telson was ribbed and pitted (=prickly), thereby differing from the spines known as *C. leptodactylus* (M'Coy).

There is also a well-preserved *small* specimen (M. P. G. x $\frac{1}{9}$, 'Catal.' 1878, p. 142), with its carapace measuring only 25 mm. in length and 11 mm. in height, from the Lower Ludlow of Bow Bridge, Ludlow. This is labelled '*C. leptodactylus*,' and belongs to the same species as the foregoing. Its caudal appendages are perfect, with the telson (25 mm.) about one-third of the length of the whole animal; but they differ from M'Coy's *C. leptodactylus*, for they are not only ribbed or ridged, but the telson was prickly; the laterals were probably rather more than half its length. Specimen M. P. G. D $\frac{22}{13}$, however, from Dudley, is a thin spiniform fragment, faintly striated, like *C. leptodactylus*.

Altogether the telson (style) and stylets of these specimens have a very close resemblance to those known as *C. Murchisoni* (see above, p. 336). One example, from Dudley, described and figured as such by H. Woodward in the 'Geol. Mag.' vol. iii. p. 204, pl. x. fig. 8 (stylets and the upper moiety of the style, 90 mm., even more than 5 inches long when perfect), was doubtlessly proportionate to the large carapace, M. P. G. x $\frac{1}{5}$, above alluded to, as belonging to an animal more than 12 inches long; the carapace, exposed segments, and the telson being each a third of the whole length.

Other good specimens of these caudal appendages are :—

Ludlow Museum, C. Lower Ludlow; Leintwardine.[1] Lower portion of the style and stylets, 130 mm. ($5\frac{1}{8}$ inches).

[1] This is mounted with specimen D as one specimen; but the discrepancy between the two parts is readily seen. It is referred to in the Rev. J. D. La Touche's 'Geol. Shropshire,' &c. p. 77.

Owens College Museum. From near Ludlow. Style and stylets, not perfect, 105 mm.

M. P. G. $\frac{23}{36}$, 'Catal.' 1878, p. 118. Leintwardine. Style, 103 mm. This and a piece of a carapace associated are labelled '*C. tyrannus*, Salter.'

Mr. Morgan's collection: Cwm-y-sul, near Welshpool (Wenlock Shale). Fragment of style, with stylets, 95 mm.

Ludlow Museum, P. Lower Ludlow; Trippleton, near Leintwardine. Lower part of style and stylets, 80 mm.

Oxford Mus. B, telson about 105 mm. (more than 4 inches); also C and D. The head or proximal end of the telson is marked with longitudinal wrinkly lines. From near Ludlow.

Broken pieces:—

Murchison's, fig. 10, pl. 4, 'Sil. Syst.' (fig. 1, pl. 19, 'Siluria'), Upper Ludlow beds. One piece measures 92 mm., and more, if the piece lying at its end belonged to it.

Woodward's fig. 9 (M.P.G. $\frac{17}{15}$, 'Catal.' p. 84), Casterton, Low Fell, Kirkby-Lonsdale; Wenlock Shale. Fragments, 50 mm.

Cambridge Museum, *b*/7. Upper Ludlow beds; Benson Knot, Kendal. Fragment, 43 mm.

M. P. G. x $\frac{1}{29}$, 'Catal.' p. 142. Upper Ludlow; Benson Knot, Kendal. Fragments, 40 mm.

Cambridge Museum (Marr Coll.). Upper Coldwell beds = Wenlock; south of Coldwell quarry, Windermere. Part of style and ends of stylets, 40 mm.

Small fragments, smooth (? *Murchisoni*); straight and ribbed; curved and ribbed (? *Murchisoni*); M. P. G. x $\frac{1}{30}$, $\frac{1}{31}$, $\frac{1}{32}$; from the Downton Sandstone; Kington, Herefordshire.

Strongly ribbed and pitted (= spinose), British Museum; Bury Ditch, Salop; and Oxford Mus. D, Ludlow.

Both in M'Coy's *C. leptodactylus* and *C. Murchisoni* (the latter = Salter's *C. leptodactylus*, in part, and his *C. tyrannus* and *C. gigas*) the last abdominal segment is striated with straight, somewhat inosculating, raised lines; and the other segments, where preserved, are similarly marked. A somewhat crushed specimen from Danefield, Kington, Herefordshire (Lower Ludlow), M. P. G. x $\frac{1}{2}$ 'Catal.' p. 141, showing a terminal segment with similar nearly straight, but wriggly, inosculating, thin riblets, and ridged and fluted caudal appendages, as far as preserved, has been labelled '*C. gigas*' by Salter; but this may well belong to the series here placed as *C. Murchisoni*; *C leptodactylus* being restricted to M'Coy's specimens and figs. 7, 7*a*, 7*b*, and a few other slender and simply striate forms. The carapace belonging to these is not yet known. It is quite possible that these rare and thinner styles and stylets may have belonged to some variety of *C. Murchisoni*. In this case a separate specific name is not required for them, and they should be merged in *C. Murchisoni*, as arranged in H. Woodward's 'Catal. Brit. Foss. Crust.' 1877, p. 71.

There is little or no doubt that the figure given by Mr. Salter in the 'Catal. Cambr. Silur. Fossils,' 1873, pp. 16, 164, and 178, as illustrative of the genus, is *C. Murchisoni*, as here defined. The *eye-spot*, however, and the *hinge-'oints* are, in our opinion, superfluous and not substantiated.

The Synonyms of CERATIOCARIS MURCHISONI (Agassiz), 1839 :—

1839. *Onchus Murchisoni*, Agassiz in 'Silur. Syst.' p. 607, pl. 4, fig. 10 (not figs. 9 and 11); and *Onchus*, fig. 63 ?, and Ichthyodorulite, fig. 64.
1851. *Leptocheles* (*Murchisoni*), M'Coy. 'Synops. Brit. Palæoz. Foss.' fasc. 1, p. 176.
1853. *Leptocheles Murchisoni* (Agass.), M'Coy. 'Quart. Journ. Geol. Soc.' vol. ix. p. 13 (omitting allusion to figs. 9 and 11, 'Sil. Syst.').
1854. *Leptocheles Murchisoni* (M'Coy), Murchison. 'Siluria,' 1st ed. p. 236, pl. 19, figs. 1, 2, and *sp.* fig. 3.
1859. *Leptocheles Murchisoni* (M'Coy), Murchison. 'Siluria,' 2nd ed. (3rd including 'Sil. Syst.'), pp. 263, 538, pl. 19, fig. 1 (2 and 3 ?).
1860. *Ceratiocaris Murchisoni* (M'Coy), Salter. 'Ann. Mag. Nat. Hist.' ser. 3, vol. v. p. 157.
1866. *Ceratiocaris Murchisoni*, H. Woodward. 'Geol. Mag.' vol. ii. p. 205, pl. 10, figs. 8 and 9.
1867. *Leptocheles Murchisoni* (M'Coy). Salter, in 'Siluria,' 4th ed. including 'Sil. Syst.' p. 134, pl. 19, figs. 1 and 2.
1867. *Leptocheles* (*Ceratiocaris*) *Murchisoni* (M'Coy). Salter, in 'Siluria,' 4th ed. p. 237, pl. 19, fig. 1 (2, 3*t*).
1867. *Ceratiocaris Murchisoni* (Agass.), Salter, in 'Siluria,' 4th ed. p. 516, pl. 19, figs. 1 and 2.
1877. *Ceratiocaris Murchisoni* (M'Coy), H. Woodward. 'Catal. Brit. Foss. Crust.' p. 71.
1884. *Ceratiocaris Pardoensis*, La Touche. 'Geology of Shropshire,' p. 77, pl. 17, fig. 563.
1884. *Ceratiocaris leptodactylus*, La Touche. 'Geology of Shropshire,' p. 77, pl. 17, fig. 566 (young *C. Murchisoni*).

The Synonyms of CERATIOCARIS LEPTODACTYLUS, M'Coy, founded on certain slender tail-spines, which may have belonged to a varietal form of *C. Murchisoni* (Agassiz) :—

1849. *Pterygotus leptodactylus*, M'Coy. 'Ann. Mag. Nat. Hist.' ser. 2, vol. iv. p. 394.
1851. *Pterygotus leptodactylus*, M'Coy. 'Synops. Brit. Palæoz. Foss.' fasc. i. p. 176, pl. 1 E, figs. 7, 7*a*, 7*b* (not figs. 7*c*, 7*d*).
1853. *Leptocheles leptodactylus*, M'Coy. 'Quart. Journ. Geol. Soc.' vol. ix. p. 13.
1859. *Leptocheles leptodactylus* (M'Coy), Murchison. 'Siluria,' 2nd (3rd) ed. pp. 263, 538.
1860. *Ceratiocaris leptodactylus* (M'Coy), Salter. 'Ann. Mag. N. H.' ser. 3, vol. v. p. 157.
1867. *Leptocheles* (*Ceratiocaris*) *leptodactylus* (M'Coy). Salter, in 'Siluria,' 4th ed. (including 'Sil. Syst.'), p. 237.
1867. *Ceratiocaris leptodactylus* (M'Coy). Salter, in 'Siluria,' 4th ed. (including 'Sil. Syst.'), p. 516.
1873. *Ceratiocaris leptodactylus*, Salter. 'Catal. Camb. Sil. Foss.' p. 164.

Taking Mr. Salter's description of the carapace of '*leptodactylus*' and the appendages of '*Murchisoni*' as really both belonging to the latter, and the more slender caudal spines (*leptodactylus* of M'Coy) as belonging to a variety of the latter, we have looked for the two-inch oblong carapace which Mr. Salter thought he had found for *Murchisoni* ('Ann. Mag. Nat. Hist.' *l.c.*), but we have not met with it at Ludlow, as led to expect by his remarks; nor is it in the Museum of Practical Geology, to which also he refers us. Indeed, we cannot help thinking that some confusion of the specimens is hereby indicated.

The carapace of *C. Murchisoni* (as defined by us) is pyriform, or acutely subovate, deep behind, narrow in front; gently convex on the back; outlined by a bold elliptical curve on the ventral margin, which rises up to form with the dorsal edge a sharp angle in front, above the

median line of the valve; but this and other features were varied by age and sex, and have been modified by pressure in the different specimens. The antero-ventral margin is sometimes indrawn, making the point in front more acute. The hinder margin is truncate with an elegant ogee curve, full below, and ending above in the postero-dorsal angle, often but not always sharply defined. In some cases the ventral margin is much deeper than in others. Some fragments of carapaces from Leintwardine (Ludl. Mus. O., and M. P. G. $\frac{23}{36}$) are ornamented with longitudinal lines or striæ of varying strength.

Seven abdominal segments are usually exposed.

Good specimens of *C. Murchisoni* (Agass.):—

M. P. G. x $\frac{1}{5}$.—Carapace, 125 × 55 mm., with acute prow. Smooth, longitudinal linear ornament. Long form of carapace. Leintwardine.

M. P. G. x $\frac{1}{7}$.—Carapace, 60 × 28 mm. Smooth and glazy.
Seven segments, about 50 mm. (the last one about 20 mm.) Telson crushed. Long form of carapace. Leintwardine.

Ludl. Mus. D.—Carapace, 50 × 30 mm. Smooth.
Seven segments, 55 mm. (the last one 20 mm.) Some with straight striæ.
Telson imperfect. Short form of carapace. Leintwardine?

Ludl. Mus. B.—Carapace, about 50 × 30 mm. Short form of carapace.
Exposed segments (crushed up), 50 mm. With straight, wriggly striæ.
Telson broken. Leintwardine.

M. P. G. x $\frac{1}{6}$.—Carapace, 40 × 20 mm., with acute prow. Smooth and glazy; rough at the place of the teeth.
Five? segments, about 30 mm. Long form of carapace. Leintwardine.

M. P. G. x $\frac{1}{9}$.—Carapace, 25 × 11 mm. Small, smooth, sharp in front, marked by teeth inside.
Seven? segments, 28 mm. (the last one 14 mm.) Linear ornament.
Telson, 25 mm. Ridged and pitted (spines). (Stylets about 12 mm. Ridged.) Long form of carapace. The whole animal $3\frac{1}{8}$ inches in length. Bow Bridge, near Ludlow.

Ludl. Mus. A.—Carapace, 24 × 13 mm. Small, smooth, subovate, sharp in front.
Seven segments, 30 mm. (the last one 12 mm.) Longitudinally striate.
Telson imperfect (12 mm. preserved). Medium form of carapace. Leintwardine?

Oxford Mus. J, K, and Q.—Small individuals in the Grindrod Coll. from the Lower Ludlow, with features corresponding with those of *C. Murchisoni*.
K is a carapace especially agreeing in form, though measuring only 15 × 6 mm. J is still smaller; it is much crushed, and about 8 × 4 mm., with an abdomen of 6 segments, probably imperfect, 9 mm. In Q the carapace (18 × 10 mm.) has been misshaped by pressure; the abdomen was about 7 mm.; and the little telson was strongly ridged, and at least 10 mm. long.

Addendum.

1853. *Dithyrocaris Murchisoni* (Agass.), Geinitz. 'Verstein. Grauwackenformation in Sachsen,' u.s.w. Heft ii. p. 24, pl. 19, fig. 13.

1866. *Ceratiocaris Murchisoni*, Jones. 'Ann. Mag. Nat. Hist.' ser. 3, vol. xviii. p. 40.

This is the distal end of a tapering, costulate telson (or stylet ?), and is quite comparable with *C. Murchisoni* (Agassiz), as indicated by Dr. H. B. Geinitz. It was obtained from the Silurian Grauwacké beds of the Gunzenberg, between Möschwitz and Pöhl, near Plauen, together with Graptolites, Orthoceras, and Pterinea.

2. Ceratiocaris Ludensis, H. Woodward.

1871. *Ceratiocaris Ludensis*, H. Woodward. 'Geol. Mag.' vol. viii. p. 104, pl. 3, fig. 3.
1884. *Ceratiocaris Ludensis*, Jones and Woodward. 'Geol. Mag.' dec. 3, vol. i. p. 396.

This large and indeed gigantic *Ceratiocaris*, represented by seven abdominal segments, with the caudal appendages of telson and two stylets, in the Ludlow Museum, has been described in the 'Geol. Mag.' for March 1871, and illustrated with a reduced figure. The carapace is there estimated as having probably been eight inches in length. The segments giving eight inches, and the telson being about nine inches in length, the animal would be more than two feet in total length. As pointed out in the paper referred to, the telson is certainly the longest known. Thus we find the relative proportions to be for *C. Ludensis*, H.W., 144; *C. Murchisoni* (Agass.) 128 (as defined above); *C. Deweii* (J. Hall), 100; *C. Bohemica*, Barr. (Brit. Mus.), 84; *C. stygia*, Salter, 32; *C. Nœtlingi*, F. Schmidt, 26; *C. papilio*, Salter, 16.

The segments are ornamented along the back with imbricated or lattice-like raised angular lines, which pass downwards on the sides into oblique and then curved wrinkly lines, and these on some of the segments form an irregular reticulation at the anterior margin. The ultimate segment is striated longitudinally with interrupted and inosculating lines. The spines are stout, tapering slowly, slightly curved inwards (downwards), delicately ribbed, and bear close-set marks of the bases of small spines between or on some of the ridges.

This fine specimen is imbedded in the greenish-grey, sandy, laminated mudstone of the Lower-Ludlow series, at Church Hill, Leintwardine, near Ludlow, with Graptolites. It was found by the late Mr. H. Pardoe, and is preserved in the Ludlow Museum.

3. Ceratiocaris papilio. Salter.

1859. *Ceratiocaris*, Salter. In Murchison's 'Siluria,' 2nd (3rd) edit. p. 262, woodcut fig. 1, p. 538.
1860. *Ceratiocaris papilio*, Salter. 'Ann. Mag. Nat. Hist.' ser. 3, vol. v. p. 154, woodcut fig. 1, and p. 155.
1865. *Ceratiocaris papilio*, Salter and H. Woodward. 'Catal. and Chart Foss. Crust.' p. 17 (not fig. 5).
1865. *Ceratiocaris papilio*, H. Woodward. 'Geol. Mag.' vol. ii. p. 403, pl. 11, figs. 1 and 2.
1867. *Ceratiocaris papilio*, Salter. In 'Siluria,' 3rd (4th) edit. p. 236, woodcut fig. 1 (not fig. 2), and p. 516.
1873. *Ceratiocaris papilio*, Salter. 'Catal. Camb. Sil. Foss.' p. 178.
1873. " " R. Etheridge, jun. 'Mem. Geol. Surv. Scotl. Expl. Map 23,' pp. 55, 56.
1876. *Ceratiocaris papilio*, Armstrong and others. 'Catal. W.-Scot. Fossils,' p. 24.
1877. " " H. Woodward. 'Catal. Brit. Foss. Crust.' p. 71.
1878. " " Huxley and Etheridge. 'Catal. Camb. Sil. Foss.' p. 142.

Of the two species, so abundant in the Upper-Ludlow Shales of the Logan Water, near Lesmahago, in Lanarkshire, and described (unfortunately without good figures) by J. W. Salter in the 'Ann. and Mag. Nat. Hist.' for March 1860, we have examined many good specimens. As mentioned by Salter, one (*C. papilio*) has the carapace more oblong than the other (*C. stygia*), which is deepened by a greater or less angularity on its ventral margin. In the woodcut diagrams at p. 154 of his

memoir, fig. 1 is the oblong form, and figs. 2 and 3 have the deep ventral angle (*C. stygia*), and yet they are all there termed *C. papilio*, evidently from oversight. In the Lesmahago district multitudes of the two species seem to have been imbedded in the black mud (now shales); and frequent references to these interesting deposits are made in 'Siluria,' 'Memoirs of the Geological Survey of Scotland' (especially 'Explanation of Map 23,' p. 49, &c.), in other works on Scottish Geology, in geological manuals &c., and in Dr. J. R. S. Hunter's papers in the 'Trans. Geol. Soc. Glasgow,' vol. vii. pp. 56, 272, &c.

Carapace sub-oblong; straight on the back, gently curved below; like the prow of a boat in front, and truncate with an ogee curve behind. The anterior extremity is rather sharp and is rarely preserved; it slopes with a gentle curve downwards and backwards from the antero-dorsal angle to the ventral margin. The latter is somewhat convex in outline, with its greatest fulness near the middle and rather forward, but varying with every specimen, all being more or less squeezed out of their true shape. The front moiety usually keeps its shape more truly than the posterior region, of which sometimes the dorsal angle (as in Brit. Mus. '41896,' '41897'), and sometimes the boldly-curved ventral portion (as in Brit. Mus. '41894,' '58669'; Cambridge Mus. *b*/135; and M. P. G. x $\frac{1}{15}$) becomes the more prominent. The surface of the valves is delicately striate, with longitudinal lines, curving parallel with the ventral margin, and coarser below than near the back. In some specimens the lines are seen to converge at, or rather, as it were, to start from, the postero-dorsal angles. The body-segments are obliquely striated. The telson (style), relatively stout, and very little longer than the laterals or stylets, was faintly ridged and perhaps prickly or spinose. The whole adult animal was probably from four to six inches long.

Having seen but few specimens in which the caudal appendages are well preserved in their place (as in Brit. Mus. '41894') we get only few good measurements.

Mr. Salter says that only three or four of the abdominal segments were free (external to the carapace), but probably there were even five; for in one specimen (Brit. Mus. '58669') five segments of large size, now loose and reversed, were probably exposed beyond the carapace; and in another (Brit. Mus. '41895') four, with an imperfect fifth, have been shifted out of place. The segments, excepting the last one, appear in their compressed condition to be half as long as high, and the last one as long as three of the others.

In Brit. Mus. '41894,' the carapace is 60 mm. long by 30 mm. deep (or high), and probably once rather deeper, having suffered from pressure. The penultimate segment is 10 mm. long, and if there were four of that length (40 mm.), with the ultimate segment, the body-rings would be nearly 80 mm. The telson was 25 mm. (stylets 18 mm.) Thus, altogether, the animal was about 152 mm., or 6 inches, in length.

Brit. Mus. '58669' has a longer (narrowed) carapace, five body-rings, and a broken telson; altogether, $6\frac{1}{4}$ inches long.

In another, but smaller, individual (Brit. Mus. '41895') the carapace, 40×20 ? mm.; segments, 40 mm., but shortened; and style, about 20 mm, (stylets, 15 mm. each), make about 100 mm., or four inches, of total length.

In ten good specimens from Lesmahago we have seen two of carapace only; and in all the others the body-portion is shifted, and in six of them

it is quite reversed—that is, lying at the anterior instead of the posterior end, as described by Mr. Salter ('Siluria,' 1867, p. 236, &c.).

The specimen Cambridge Mus. *b*/135 has the rostrum lying at an angle across the anterior extremity.

Of *C. papilio*, good specimens from Lesmahago:—

Cambridge Mus., *b*/135. M. P. G. x $\frac{1}{15}$, x $\frac{1}{22}$.

Brit. Mus. 41894, 41895, 41896, 41897, 45161, 47989, 58669.

We have seen also some fossil carapaces from Benson Knot, Kendal (Upper Ludlow) which agree perfectly in form and proportions with *C. papilio* from Lesmahago, also in ornament, except that the postero-dorsal convergence of the striæ is not present. These are Brit. Mus. some of those marked '44342'; M. P. G. x $\frac{1}{4}$ ('Catal.' 1878, p. 141); and Cambridge Mus. *b*/35. They range from 65 mm. long and 32 mm. high to 75 × 40 mm. Also a large imperfect specimen and some fragments in brown shale from Linburn, near Muirkirk (Brit. Mus., all marked '58878'). The specimen *b*/35 is included in *C. inornata*, M'Coy, by Mr. Salter, 'Catal. C. S. Foss.' 1873, p. 177.

Moreover, the specimen N in the Ludlow Museum has the proportions and appearance of *C. papilio*, as far as it is preserved (wanting the antero-dorsal angle), from Church Hill, Leintwardine.[1]

4. Ceratiocaris stygia, Salter.

1859. *Ceratiocaris*, Salter. In Murchison's 'Siluria,' 2nd (3rd) ed. p. 262, woodcut fig. 2.
1860. *Ceratiocaris stygius*, Salter. 'Ann. Mag. Nat. Hist.' ser. 3, vol. v. p. 154, woodcut figs. 2, 3 (fig. 1 is *C. papilio*).
1865. *Ceratiocaris papilio*, Salter and Woodward. 'Cat. and Chart Foss. Crust.' p. 17, fig. 5.
1867. *Ceratiocaris stygius*, Salter. In 'Siluria,' 3rd (4th) ed. p. 236, woodcut fig. 2, and p. 517.
1873. *Ceratiocaris stygius*, Salter. 'Cat. Camb. Sil. Foss.' p. 178.
1873. " " R. Etheridge, jun. 'Mem. Geol. Surv. Scotl. Expl. Map 23,' pp. 55, 56.
1876. *Ceratiocaris papilio*, F. Rœm. 'Leth. geogn.' Th. i. 'Leth. pal.' pl. 19, fig. 4.
1876. " *stygius*, Armstrong and others. 'Cat. W.-Scot. Fossils,' p. 24.
1877. " " H. Woodward. 'Catal. Brit. Foss. Crust.' p. 73.
1878. " " Huxley and Etheridge. 'Cat. Camb. Sil. Fossils,' p. 142.

Carapace-valves trapezoidal; back straight, but curving down for a short distance to the mucronate dorsal angle of the anterior edge, which then slopes, with a slight convexity and at a sharp angle, downwards and backwards, to about the middle of the ventral margin, where the valve is deepest (highest); the other half of the ventral edge rises slowly with a straight or nearly straight oblique edge to the blunt postero-ventral corner, whence the truncate hind margin rises, with a gentle concave curve, to the sharp postero-dorsal angle. When the valves are spread open a triangular space is left between the antero-dorsal angles. This condition and the shape are well shown in the specimen M. P. G. x $\frac{1}{13}$. The outline is often modified by pressure in

[1] The very rich localities for these Silurian Phyllopods in the neighbourhood of Ludlow are enumerated and described in the Rev. J. D. La Touche's 'Handbook of the Geology of Shropshire, 1884,' pp. 26, 27, especially Ludford Lane, Bow Bridge, Leintwardine, Church Hill, and Trippleton Farm. See also the Rev. W. S. Symonds' 'Record of the Rocks,' 1872, p. 194, &c. for notices of Ludlow and its environs from a geologist's point of view.

other positions; but not to quite so great an extent, as the shape of *C. papilio* is altered by squeeze in some instances. The valves are delicately striate, with longitudinal lines curving parallel with the ventral edge, and crowded at the postero-dorsal angles. The body-segments, of which probably five were outside the carapace (though often the segments seem to have been pushed back within the carapace after death), are marked with delicate, raised, oblique, wrinkly lines on the sides, and ornamented on the back with an imbrication of angular lines, which pass down into the lateral oblique wrinkles, M. P. G. x $\frac{1}{19}$ and $\frac{1}{20}$. These joints are sometimes more than twice as high as long. The last one is as long as three of the others. The telson is apparently in some cases about half as long again as the stylets (as 50 is to 30); and some specimens show traces of thin costulæ, and perhaps of prickles. The whole adult animals were from 4 to 8 inches long.

Specimen M. P. G. x $\frac{1}{20}$ has the rostrum and teeth squeezed out loose near the front end. A large individual, Cambridge Mus. *b*/65, measures—

Carapace		83 × 55 mm.
Four segments	40	65 mm.
Last segment	25	
Telson		50 ,,
		198 mm., or nearly 8 inches.

A small specimen, M. P. G. x $\frac{1}{13}$, measures—

Carapace		40 × 26 mm.
Four segments	20	30 mm ?
Last segment	10 ?	
Telson		30 ,,
About		100 mm., or nearly 4 inches.

C. stygia was rather larger than *C. papilio*; its telson was larger; the carapace is markedly distinct by its trapezoidal outline, deep ventral region, and mucronate antero-dorsal angle, which was not nearly so often lost in fossilisation as the front angle of *C. papilio*. In its rostrum, teeth, superficial ornament of carapace and of body-rings, it seems to have closely resembled *C. papilio*. In ten good specimens from Lesmahago, two are simple carapaces; three have body-segments in places, and five have them shifted or reversed. In this respect *C. stygia* seems to have been rather less liable to the dissolution of the membranous attachments of the body than its associate *C. papilio*.

A postero-dorsal fragment in Cambridge Museum (Marr Coll.), from the Denbighshire series (Wenlock), at Dinasbran, Llangollen, showing fine striæ above, and coarse striæ below, and the usual convergence of striæ, belongs probably to *C. stygia*.

An anterior moiety of a valve from near Ludlow is in the Grindrod Coll., Oxford Mus. G.

Good specimens of *C. stygia* from Lesmahago are Cambridge Mus. *b*/136, *b*/65 (the last is referred to as *C. papilio*, evidently by mistake, in 'Cat. C. Sil. Foss.' p. 178); M. P. G. x $\frac{1}{13}$ and $\frac{1}{14}$, x $\frac{1}{16}$, x $\frac{1}{19}$, x $\frac{1}{20}$, x $\frac{1}{21}$; and B. M. 41898, 45154, 45155, 45156.

In the 'Mem. Geol. Surv. Scotl. Expl. Map 23,' 1873, at p. 49, Mr. R. Etheridge, jun., enumerates the places near Lesmahago and Muirkirk, in Lanarkshire, where *Ceratiocarides* have been found by the Surveyors, namely—

Ceratiocaris papilio, Salter, at Dunside (Logan Water), Eaglinside Burn, Logan Water (2 m. S. of Lesmahago), and Linburn.
Ceratiocaris stygia, Salter, at Kip Burn (Logan Water), Eaglinside Burn, and Linburn.
Ceratiocaris, caudal appendages, at Long Burn (Logan Water), Dunside (Logan Water), Logan Water (6 m. S.W. of Lesmahago), Lann Burn, and Douglas Water.

Abdominal segments and appendages probably belonging to *C. stygia* are:—

Oxford Museum, E, seven segments and two spines, imperfect. The former ornamented with angles and oblique lines, the latter with a longitudinal lineation. Leintwardine.

B. M. '58878,' Linburn, Muirkirk. A telson, not quite perfect at base, 35 mm. long, associated with some obliquely-striate segments.

B. M. '41899,' Lesmahago. Four segments, 27 mm., and M. P. G. x $\frac{1}{25}c$, four segments, 30 mm., and in each case two short ensiform stylets attached (style wanting).

B. M. '41900' and '41901,' Lesmahago. Three abdominal segments, obliquely striate, and an ultimate segment with both oblique and straight striæ, probably due to two layers of the test. Telson, 30 mm. long; and two ensiform stylets, each about 13 mm. long.

M. P. G. x $\frac{1}{25}a$, $\frac{1}{25}b$, $\frac{1}{25}d$, Logan Water, Lesmahago. Segments with oblique striæ (one ultimate segment has straight striæ), not well preserved. Probably *C. stygia*, as named in the 'Catal.' 1878, p. 142.

One of the specimens in the Brit. Mus. marked '59648,' from Lesmahago, is a small acute-ovate carapace (25 × 15 mm.), to which is attached a complete, but somewhat crushed body of 13–14 segments, 6–7 (15 mm.) of which are external, and have appended two caudal spines, of which the strongest may be the telson (12 mm. long), and the other, nearly as long, one of the stylets.

At first sight this looks like the small *C. Murchisoni*, Ludl. Mus. A., but it differs considerably in details. If it be not a distinct species, it may be the young of *C. stygia*.

On another of the specimens, B.M. '59648,' from Lesmahago, are three loose small *bodies*, without carapaces. The largest has 13 or 14 segments, 45 mm., some of which are obliquely striate. Five measure 25 mm., and the last one 10 mm., equal to three of the others. The telson is 20 mm. long. Another such specimen, smaller and narrower, 35 mm. long, has 14 (?) segments; the last one 7 mm. long; appendages imperfect.

These may be the loosened and shifted abdomens of young individuals of *C. stygia* or *C. papilio*, both common at Lesmahago. They cannot be mistaken for the Carboniferous *Acanthocaris*, Peach, or the Devonian *Campecaris*, Page.

5. Ceratiocaris inornata, M'Coy.

1851. *Ceratiocaris inornatus* (Salter MS.), M'Coy. 'Brit. Pal. Foss.' p. 137, pl. 1 E., fig. 4.
1854. „ „ Morris. 'Catal. Brit. Foss.' 2nd edit. p. 102.
1859. „ „ Salter. In 'Siluria,' 2nd (3rd) edit. p. 532.
1860. „ „ „ 'Ann. Mag. Nat. Hist.' ser. 3, vol. v. p. 156.
1867. „ „ „ In 'Siluria,' 3rd (4th) edit. p. 516.
1873. „ „ „ 'Catal. Camb. Sil. Foss.' pp. 177, 178.
1877. „ „ H. Woodward. 'Catal. Brit. Foss. Crust.' p. 71.

This is the third of M'Coy's original species. The specimen in the

Cambridge Museum has its carapace ovate-oblong or somewhat boat-shaped in outline, 50 mm. (2 inches) long, height 18 mm.; moderately convex; straight or very slightly arched above and more strongly arched below (both edges are partly imbedded in the matrix of the original specimen, *b*/5, M'Coy's fig. 4). The anterior end (damaged) was neatly rounded, sloping up gracefully from below. The posterior is obliquely truncate from above downwards and outwards, with the postero-dorsal angle distinct, and the postero-ventral angle prominent and blunt. There is no eye-spot. Traces of longitudinal striæ are visible on the impressions of the valves in the grey, micaceous, Upper-Ludlow sandstone, from Benson Knot, near Kendal, Westmoreland; two specimens (one of them good) are in the British Museum, No. '44342,' from the same locality.

The foregoing description does not quite tally with the account of the species in the 'Brit. Pal. Foss.' p. 137, nor with that in the 'Ann. Mag. N. H.' *l. c.*, but is based on the original specimen and not on the *restored* figure in the 'Brit. Pal. Foss.' The figure annexed by Mr. Salter to his note on *C. inornata* in the 'Catal. Camb. Sil. Foss.' 1873, p. 178, is used also in connection with two other species at p. 16 and p. 164. In the latter case it is probably intended for '*C. leptodactylus*,' which we recognise as *C. Murchisoni*.

C. inornata approaches *C. papilio* in form in some cases, but we think that they are quite distinct species. There are some small carapaces, one from Lesmahago, B. M. '59648,' very near to *C. papilio* in form, and measuring 34 × 13 mm., and one from Benson Knot, B. M. '44342,' measuring 35 × 14 mm. These proportions are different from those of *C. papilio*. These two are rather smaller than M'Coy's original *C. inornata* (about 50 × 20 mm.), but have the same proportions, the normal height being $2\frac{1}{2}$ of the length; whilst *C. papilio* is larger and has less height in proportion, the length being only twice the height, or even less.

6. Ceratiocaris Oretonensis, H. Woodward.

1871. *Ceratiocaris Oretonensis*, H. Woodward. 'Geol. Mag.' vol. viii. p. 105, pl. 3, fig. 1.
1878. *Ceratiocaris Oretonensis*, H. Woodward. 'Cat. Brit. Foss. Crust.' p. 71.

This Carboniferous species, described in the 'Geol. Mag.' for March 1871, approaches closely to some of the forms of *Ceratiocaris* found in the Upper Silurian of Benson Knot—namely, *C. inornata*, M'Coy. The carapace (50 × 22 mm.) is larger, however, without attaining the size and proportions of *C. papilio*, which is also found there, and is not without an apparent relationship to the former, as noticed above. In again examining the specimens, we find that the anterior end is not so much rounded as in fig. 1, but is slightly and obliquely truncate; and the antero-ventral margin is more sloping and less convex; thus the greatest depth of the carapace is in the hinder half. Four specimens from the Yellow Carboniferous Limestone of Oreton and Farlow, Worcestershire, not well preserved. The indistinct, 'eye-spot,' mentioned at p. 105, is very problematical, and may have been caused by pressure on some internal organ (teeth?).

7. Ceratiocaris truncata, H. Woodward.

1871. *Ceratiocaris truncatus*, H. Woodward. 'Geol. Mag.' vol. viii. p. 106, pl. 3, fig. 2.
1878. *Ceratiocaris truncatus*, H. Woodward. 'Cat. Brit. Foss. Crust.' p. 72.

The smaller species occurring with the last (*C. Oretonensis*) was described and figured with it in 1871. The carapace (35 × 15 mm.) is well figured, except that (as the author remarks, p. 106) the slightly concave truncation of the hinder end is not well rendered by the artist. Its smaller size, sharp antero-dorsal angle, and nearly even ventral curve, distinguish it from its associates, but scarcely separate it, as far as outline is concerned, from some specimens of *C. inornata* at Benson Knot.

8. Ceratiocaris solenoides, M'Coy.

1849. *Ceratiocaris solenoides,* M'Coy. 'Ann. Mag. N. H.' ser. 2, vol. iv. p. 413, with woodcut.
1851. *Ceratiocaris solenoides,* M'Coy. 'Brit. Palæoz. Foss.' fasc. i. p. 138, pl. 1 E, figs. 5, 5*a*.
1854. *Ceratiocaris solenoides,* Morris. 'Catal. Brit. Foss.' 2nd ed. p. 173.
1860. *Cultellus? (Ceratiosolen?) rectus,* Salter. 'Ann. Mag. N. H.' ser. 3, vol. v. p. 160.
1873. *Ceratiocaris solenoides,* Salter. 'Cat. Camb. Sil. Foss.' p. 178.
1877. „ „ H. Woodward. 'Catal. Brit. Foss. Crust.' p. 71.

Prof. M'Coy founded the genus on this species and *C. elliptica* in 1849.

The original specimens in the Cambridge Mus. (*b*/40, *b*/41) are not exactly drawn in M'Coy's figs. 5 and 5*a*. The carapace is elongate, subcylindrical, slightly convex on the sides, with an even elliptical anterior curve, and an oblique truncation posteriorly. There are faint traces of longitudinal striæ on the hollow impressions of the valves in the matrix, and there is a slight trace of the ventral rim. The large one is 43 mm. long (fig. 5); the smaller specimen, fig. 5*a*, 27 mm., is apparently broken behind, but does not show the double valve there as given in the figure; we cannot distinguish any 'nuchal furrow,' nor is there any 'eye-spot': a mark consisting of two minute adventitious pits in the anterior third of one of the specimens, and a little hole in another, have been mistaken for it. Mr. Salter thought these little fossils were Molluscan;[1] but they certainly may well claim to be Phyllopods. There are other specimens in the Cambridge Mus.; also two small individuals, one 19 mm. and the other only 10 mm. (marked *f*/142) in length. In the Brit. Mus. there are four, rather large, but not well preserved specimens ('44342'). All the above come from the Upper-Ludlow grey micaceous sandstone of Benson Knot, near Kendal, Westmoreland.

9. Ceratiocaris gobiiformis, *sp. nov.*

A form closely approaching *C. solenoides* in shape, but smaller, more acute in front, usually more vertically truncate behind, and much more convex on the ventral border, accompanies *C. solenoides* in the Upper-Ludlow sandstone of Benson Knot. One of the specimens marked *b*/8, Cambridge Mus. is 27 mm. long by 9 mm. high; one in the Brit. Mus., No. '44342,' is 30 by 10 mm.; M. P. G. x $\frac{1}{18}$ ('Catal.' 1878, p. 142) is 31 by 11 mm. The valves seem to have been smooth. They distantly resemble in outline a deep-bodied, blunt-headed little fish, without its tail. It is possible that this may be a varietal or sexual form of *C. solenoides*, but it seems to be sufficiently well separated from its ally to require a distinctive name, so we will refer to it as *C. gobiiformis* in our list.

[1] See 'Ann. Mag. Nat. Hist.' *l. c.* p. 159, *note*; and Sedgwick's 'Lists of Kendal Fossils,' 'Wordsworth's Letters on the Lakes,' 1843–46, Appendix.

10. Ceratiocaris Salteriana, *sp. nov.*

Six specimens in different states of preservation, from the Lower-Ludlow strata, indicate the existence of a distinct species of *Ceratiocaris*, having a nearly oblong carapace, ornamented with delicate but strong horizontal parallel lines, rather wide apart.

Specimen Ludlow Mus. K., from Trippleton, near Leintwardine, has a carapace (23×12 mm.), five (?) abdominal segments (10 mm.), and appendages, of which the style (pitted with bases of little spines) is imperfect, but a stylet measures 5 mm.

Another carapace M. P. G. $\frac{22}{14a}$, from Bow Bridge, Ludlow, well preserved, is 30×15 mm., straight on the back, rounded at the ends, the front being highest, and the greatest depth of the carapace being at the anterior third of the ventral margin. A hinder moiety of another carapace accompanies the last mentioned.

In the Cambridge Univ. Mus. *a*/694 is a similar carapace nearly as well preserved (30×14 mm.). The ventral margin has a distinct raised rim. The striæ and interspaces differ in tint of colour on the cast. Some internal organs (teeth?) have caused a little break or hole, and a derangement of the striæ in the antero-dorsal region. This specimen is from the Lower-Ludlow Shale at Dudley.

Two specimens, also from the Lower Ludlow series, L and M in the Oxford Museum (Grindrod Coll.), evidently belong to this species, though they are far from being perfect in some details.

We wish to associate this rare but distinct species of *Ceratiocaris* with the name of our deceased friend Mr. J. W. Salter, who worked so long and so well on these and allied *Phyllopoda*.

11. Ceratiocaris cassia, Salter.

1860. *Ceratiocaris cassia*, Salter. 'A. M. N. H.' ser. 3, vol. v. p. 159.
1867. " " " In 'Siluria,' 3rd (4th) edit. p. 516.
1877. " " H. Woodward. 'Cat. Brit. Foss. Cr.' p. 70.
1878. " " Huxley and Etheridge. 'Cat. C. S. Foss. M. P. G.' p. 141.

The best preserved carapace-valve (22×11 mm.) we have seen is Brit. Mus. '44342,' from the Upper Ludlow of Benson Knot; Brit. Mus. '38400,' from the Lower Ludlow of Leintwardine is also good, but is crumpled so as to have its outline modified. Originally nearly oblong, slightly arched above and below, truncate with hollow curve behind, pointed and mucronate at the upper third in front. Ludlow Mus. E. and F. and M. P. G. x $\frac{1}{1}$ ('Catal. C. S. Foss.' 1878, p. 141), seen by Mr. Salter, are not quite perfect. They are from a roadside quarry S.E. of Trippleton Farm, near Leintwardine. Ludlow Mus. F. and Brit. Mus. '39400' retain traces of the abdomen: in the latter, 15 mm. long, without appendages; in the former much less is seen, and a short telson (about 5 mm.). The carapace is horizontally striate, and the telson is minutely pitted as if it had been spinose. The ventral margin had a delicate raised rim.

Ludlow Mus. H., also from Trippleton, is a very small oval relic of a valve (13×7 mm.) possibly of *C. cassia*, and a loose abdomen of 5–6 segments (16 mm.), with a neat little set of appendages, style, 6 mm., and two stylets, each 3 mm.

Ludlow Mus. G. may be a modified carapace of *C. cassia*: no locality is recorded for it.

12. Ceratiocaris, *sp. nov.* ?

Mus. Pract. Geol. x $\frac{1}{26}$ ('Catal. C. S. Foss.' 1878, p. 142), labelled '*C. vesica*,' is a small specimen, having its carapace and abdomen preserved in place. From the Lower Ludlow of Leintwardine. It differs very much from *Physocaris vesica*, although nearly of the same size. The carapace is subtriangular, 25 mm. long and 15 mm. deep at the middle of the ventral margin. The back is straight, but curved down at both ends to meet the steep upward slopes of the lower margin. The abdomen (15 mm.) comes out, as usual, from the upper part of the hinder region. It shows obscurely four segments (the ultimate one about 6 mm.), mostly striated obliquely. The appendages have been broken off short. The carapace is somewhat crumpled, and is roughened anteriorly, probably by the presence of internal organs (such as teeth, &c.).

It is possible that this may be a very young individual of *C. stygia*, to which it somewhat approximates by its subtriangular carapace, and its obliquely-striate segments. Otherwise it must be a distinct species.

Specimen Lud. Mus. J. (from Trippleton, near Leintwardine) has a smaller but nearly similar carapace (22 × 12 mm.); nearly straight on the back, deeply curved below, and with almost equal dorsal angles in front and behind, but sharp instead of being blunt.

13. Ceratiocaris robusta, Salter.

1851. *Pterygotus leptodactylus*, M'Coy (in part). 'Brit. Palæoz. Foss.' fasc. i. p. 175, pl. 1 E, figs. 7*c*, 7*d*.
1860. *Ceratiocaris robustus*, Salter. 'Ann. Mag. N. H.' ser. 3, vol. v. p. 158.
1867. „ „ „ In 'Siluria,' 3rd (4th) edit. p. 516.
1873. „ „ „ 'Cat. Camb. Sil. Foss.' p. 164.
1877. „ „ H. Woodward. 'Cat. Brit. Foss. Crust.' p. 71.
1878. „ „ Huxley and Etheridge. 'Cat. Camb. Sil. Foss. M. P. G.' p. 142.

This species was founded on the caudal appendages of a species the carapace of which has not yet been collated. The original specimens figured by M'Coy and referred by Salter to a new species are in the Cambridge University Museum (*a*/925, fig. 7*c*; *a*/926, fig. 7*d*). The telson, 32 mm. long (longer than the figure), is straight, broadly ensiform, 6 mm. broad at its base. The stylets, 20 mm. long, are also relatively broad and ensiform or sharp-blade-like. They all seem to have once been faintly fluted and ridged or costulated. They were from Leintwardine (Lower Ludlow).

Two similar specimens, collected by the late Mr. Lightbody in Upper-Ludlow beds, 'above Ashley Moor,' are in the Owens College Museum, Manchester. One of the sets, however, has the stylets nearly as long as the style: whether this was due to variation of growth or to accident, we cannot now decide.

B. M. '39404,' from Leintwardine, belongs to the same species, though the style is rather longer (35 mm.).

Also M. P. G. $\frac{1}{17}$ ('Catal.' 1878, p. 142), from Leintwardine, seems to belong to this form. It shows two segments and appendages. Style, 40 mm.; one stylet present, broad and ensiform, 25 mm. long.

Specimen A, Oxford Mus. (Grindrod Coll.) consists of the penultimate (11 mm.), and ultimate (20 mm.) segments, with a broad style (45 mm.) and corresponding smaller stylet (25 mm.), of what seems to be a rather large *C. robusta*. The caudal spines are strong, broad, and ensiform, the style

is fluted; the stylet flat, except its marginal rims. The two segments are neatly ornamented with imbricate lozenge-shaped or sharp leaf-like lines, each angle inclosing a smaller leaf-like lattice-work, as in Barrande's *C. Scharyi*. This is in the Lower-Ludlow olive-grey laminated mudstone from near Ludlow with an Orthoceras.

Another in the same Coll. (H), from the same series, consists of four segments (35 mm., the ultimate being 15 mm.), with style (32 mm.) and a stylet (18 mm.). These spines are ensiform and broad; the stylet flat with edge-rims, the style ridged and pitted (= spinose, two lines visible). The segments are ornamented as in specimen A, but with a smaller pattern, and the penultimate and two higher segments have lateral oblique lines coming down from the angular lines which covered the back.

Two other specimens in the same Collection, from the Upper (?) Ludlow, correspond more closely with M'Coy's specimens, being short trifid sets of broad spines—one (T) with a style 28 mm. long and stylets each 15 mm., the other (S) having style 23 mm. and stylets 13 mm. In both the stylets are smooth with slight marginal rims, and the style is faintly fluted and pitted (= spinose), in T definitely along two rows, one near each margin.

Var. longa.

Specimen Ludlow Museum M. is a broad and much longer telson (at least 75 mm. long), with linear ornament, from the Lower Ludlow at Bow Bridge, Ludlow. A small part of a slightly curved ensiform stylet shows from beneath it. This may be either a variety of *C. robusta*, or possibly a distinct species.

14. CERATIOCARIS, *sp. nov.*?

In Owens College Museum, Manchester, is a very delicate little set of caudal appendages. The style (central) shows a circular section at its base (top), about 2 mm. wide, is 12 mm. long, and tapers gently to a sharp point. The lateral stylets are 8 mm. each. All are delicately ridged and fluted. From the Lower-Ludlow or Aymestry Limestone, on the old road at Mocktree; collected by the late Mr. Lightbody.

Mus. Pract. Geol. D $\frac{22}{14}$ ('Catal. C. S. Foss.' 1878, p. 118), from the Lower Ludlow at Leintwardine, is a somewhat similar little set of appendages (three spines). The middle one is the longest, 8 mm., the others 6 mm.

These may belong to a very young condition of some of the species above mentioned, or possibly to a distinct species.

In the British Museum one of those marked '58878' from Linburn, near Muirkirk, shows a style (21 mm.), tapering, with circular section at base, and apparently smooth, together with a corresponding attached stylet, 16 mm. long. Were these not smooth, they might be referred to the same species as the foregoing smaller specimens. This set differs from the appendages of either *C. papilio* or *C. stygia*.

15. CERATIOCARIS DECORA, Phillips.

1848. *Onchus decorus*, Phillips. Mem. Geol. Surv.' vol. ii. part 1, p. 226, pl. 30, figs. 5, 5*a*.
1867. *Ceratiocaris decorus*, Salter. In 'Siluria,' 3rd (4th) edit. p. 516.
1877. " " H. Woodward. 'Cat. Brit. Foss. Crust.' p. 70.

This is a small obscure style (?), 13 mm. long, from the Ludlow beds, of Freshwater-East, Pembrokeshire.

B. *Doubtful Genera.*

16. Ceratiocaris (?) ensis, Salter.

1860. *Ceratiocaris? ensis,* Salter. 'Ann. Mag. N. H.' ser. 3, vol. v. p. 159.
1867. „ „ „ In 'Siluria,' 3rd edit. p. 516.
1877. „ „ H. Woodward. 'Catal. Brit. Foss. Crust.' p. 71.

In the Grindrod Collection, Oxford Museum, specimen O, we find the original fossil described by Mr. Salter in 1860, namely, a large telson, nearly 6 inches long, lying on its side and flattened, bulbous at its base, sword-shaped, with an incurved apex, a crenatoserrate convex dorsal margin, and flat sides with sub-central lateral rib (originally lozenge-shaped in section). From the Lower Ludlow at Leintwardine, near Ludlow. Not quite perfect at point, it is 145 mm. long; 16 mm. broad at the bulb, and 13 mm. below it. We have to add that along and close to the inner (concave) edge there is a multiple row of pits (= small spines or prickles), in threes and fours obliquely set, along the upper half, below the bulbous portion; and these die out downwards in a less regular, thinner, and more scattered series. Casts of parasitic Polyzoa (?) cover the bulb and occur here and there on the spine. The arrangement of the pitting along the concave edge may indicate a distinct *generic* relationship. It reminds us of Barrande's *C. debilis*, as figured in his 'Sil. Syst. Bohême,' vol. i. Suppl. pl. 18, figs. 26–28, and pl. 31, figs. 16–19.

There is another similar but much less distinct specimen, in the same Collection, from near Ludlow.

17. Ceratiocaris (?) lata, Salter.

1866. *Hymenocaris? latus,* Salter. 'Mem. Geol. Surv.' vol. iii. p. 240.
1866. *Ceratiocaris? latus,* Salter. Ibid. p. 294, woodcut fig. 5.
1867. „ „ „ In 'Siluria,' 3rd (4th) edit. p. 516.
1873. „ „ „ 'Cat. Camb. Sil. Foss.' p. 16.
1877. „ „ H. Woodward. 'Cat. Brit. Foss. Crust.' p. 71.

The specimen is in the Cambridge Museum (*b*/299 ?), and shows 5 (?) abdominal segments crushed endwise, so as to be shortened (12 mm.) and widened (28 mm.). The woodcut referred to is a *restoration*. The specific, and even generic, relationship is obscure. From the Tremadoc Slate, at Garth, east of Portmadoc; collected by Mr. D. Homfray.

18. Ceratiocaris (?) insperata, Salter.

1866. *Ceratiocaris? insperatus,* Salter. 'Mem. Geol. Surv.' vol. iii. p. 295.
1867. „ „ „ In 'Siluria,' 3rd (4th) edit. p. 516.
1873. „ „ „ 'Cat. C. S. Foss.' p. 16.
1877. „ „ H. Woodward. 'Cat. B. F. Crust.' p. 71.

In the Cambridge Museum (A/275). Obscure remnant of an ultimate abdominal segment, with clear indications of a trifid appendage; the telson or central spine seems to be the longest, but all three are broken off above their points. The telson is about 35 mm. long. From dark-grey shales between the Lower and Upper Tremadoc Slates in a railway-cutting above the village of Penmorfa, Portmadoc. Collected by Mr. D. Homfray. Mr. Salter thought that it belonged to the same species as the foregoing.

19. CERATIOCARIS (?).

An obscure hinder moiety (25 × 12 mm.) of a carapace possibly referable to *Ceratiocaris*, is in the Mus. Pract. Geol. $\frac{13}{84}$, 'Catal. C. S. Foss.' 1878, p. 72. From the 'Upper Llandovery; Onny River.'

20. CERATIOCARIS ? PERORNATA, Salter.

1878. *Ceratiocaris perornatus* (Salter MS.), Huxley and Etheridge. 'Catal. Camb. Sil. Foss.' M. P. G. p. 142.

Very little is known of this obscure form. One specimen M.P.G. x $\frac{1}{11}$, and two in the Cambridge Museum, are only fragments (one rather more than an inch long, and the others less) of what seem to be cylindrical spines (like those of Echinoderms), about 5 mm. in diameter, two pitted all over (?) and one tuberculate. They are from the Upper Ludlow of Benson Knot, near Kendal, Westmoreland.

C. *Genera distinct from Ceratiocaris.*

21. CERATIOCARIS ? ELLIPTICA, M'Coy.

1849. *Ceratiocaris ellipticus*, M'Coy. 'Ann. Mag. N. H.' ser. 2, vol. iv. p. 413.
1851. " " " 'Brit. Pal. Foss.' fasc. i. p. 137, pl. 1 E, fig. 8.
1854. " " Morris. 'Catal. Brit. Foss.' 2nd edit. p. 103.
1859. " " Salter. In 'Siluria,' 2nd (3rd) edit. p. 538.
1860. " " " 'Ann. M. N. H.' ser. 3, vol. v. p. 157.
1867. " " " In 'Siluria,' 3rd (4th) edit. p. 516.
1873. " " " 'Catal. Camb. Sil. Foss.' p. 178.
1877. " " H. Woodward. 'Catal. Brit. Foss. Crust.' p. 71.

This interesting species, one of the first two established, is represented in the Cambridge Museum by specimen *b*/15 (M'Coy's fig. 8), and in the Museum of Practical Geology by $\frac{23}{32}$ ('Catal.' 1878, p. 118) and x $\frac{1}{10}$ ('Catal.' p. 142). The carapace is long-ovate in outline, not very convex, greatest convexity of surface and curvature of ventral margin 'at about one-third from the anterior end'; obliquely rounded in front; obliquely truncate at the upper portion of the hinder end. There is a spot like a definite ocular tubercle in the anterior fourth and above the median line of each valve, and this gives it a distant likeness to a guinea-pig's profile. The surface is neatly marked with delicate, longitudinal, parallel lines, rather far apart. The published figure of the specimen, *b*/15 (32 mm. long and 13 mm. high) is reversed, and drawn too angular behind. It came from the Upper-Ludlow sandstone of Benson Knot. Specimen M. P. G. $\frac{23}{32}$ is from the Lower-Ludlow beds of Leintwardine, near Ludlow, and is not quite so large nor so well preserved as *b*/15. Specimen M. P. G. x $\frac{1}{10}$, from the Upper-Ludlow of Combe Wood, Presteign, is larger and more ovate or elliptical than the others, but, unfortunately, is imperfect. The last two have been incorrectly labelled '*C. Murchisoni.*' In 1860 Mr. Salter thought that *C. elliptica* was only a badly preserved variety of *C. inornata* ('A. M. N. H.' *l. c.*), but in the 'Catal. Cambr. Sil. Foss.' p. 178, he recognised it as 'quite distinct.'

The above-mentioned three specimens supply the only evidence of an eye-spot in these British Ceratiocaridoid Phyllopods.[1] It is not only a generic character distinguishing them from *Ceratiocaris*, but an important

[1] The 'ocular tubercles' mentioned in the footnote at p. 236, *Siluria*, 3rd (4th) edit. 1867, are without doubt due to the presence of 'teeth' within the valves.

family distinction, of which, for the present, we do not propose to estimate the value.

22. Physocaris vesica, Salter.

1860. *Ceratiocaris (Physocaris) vesica*, Salter. 'Ann. Mag. N. H.' ser. 3, vol. v. p. 159, woodcut fig.
1865. *Ceratiocaris (Physocaris) vesica*, Salter and H. Woodward. 'Catal. Chart. Foss. Crust.' p. 17, fig. 8.
1867. *Ceratiocaris vesica*, Salter. In 'Siluria,' 3rd (4th) edit. p. 517.
1877. *Ceratiocaris (Physocaris) vesica*, H. Woodward. 'Cat. Brit. Foss. Crust.' p. 72.
1878. *Ceratiocaris vesica*, Huxley and Etheridge. 'Cat. C. S. Foss.' p. 142.

Of this curious fossil Phyllopod, described carefully by Mr. Salter in 1860, only one specimen is known—namely, 'Ludlow Museum U.' It differs slightly from Mr. Salter's figure, being larger, and showing an appearance of having been probably broken away to a little extent just above the front, so as to leave a notch and angle, which constitute the prominence in the woodcut figure. If continued over this notch the outline of the shell would possibly be that of a broad oval; whereas now it is broadly and obliquely pyriform (25×20 mm.). The relative position of the animal is supposed to be indicated by the telson occupying the upper part of the abdominal appendages attached to the fossil. There are 8–9 segments in the abdomen, which appears to come out from the lower and hinder quarter of the carapace, and is very slender near its origin, but higher at its ultimate segment (5 mm. long); altogether 30 mm. The telson itself is 11 mm. long. One lateral spine (stylet), 7 mm., is present. The whole animal is about two inches long.

It was collected by the late Mr. Salwey in the Lower Ludlow at Leintwardine, and Mr. Salter at first registered it as *Ceratiocaris inflata.*

23. Acanthocaris, B. N. Peach.

In the 'Transact. R. Soc. Edinburgh,' vol. xxx. Part I. for 1880–1 (1882) Mr. B. N. Peach gave a memoir 'On some New Crustaceans from the Lower Carboniferous Rocks of Eskdale and Liddesdale; and in Part II. for 1881–2 (1883) his 'Further Researches among the Crustacea and Arachnida of the Carboniferous Rocks of the Scottish Border.' In the first memoir he described and figured his new *Ceratiocaris scorpioides* (p. 73, pl. 7, figs. 1–1*f*), and *C. elongatus*, p. 74, pl. 7, figs. 2–2*f*. In 1883 he instituted a new genus, *Acanthocaris*, for these curious Cuma-like forms, and added a new species, *A. attenuatus* (p. 512, pl. 28, figs. 1–1*e*). *Acanthocaris* has its body much longer than the carapace, which is small, with a blunt snout-like projection in front and rounded postero-ventral side-lobes behind. Two denticulated jaws occur within the carapace near the antero-ventral margin. The total length of the animal from 1 to 2½ inches. It has a much smaller carapace and longer abdomen than *Ceratiocaris*, and the form and structure of the carapace, and the relative size and shape of the segments, are very distinctive. Mr. Peach thus describes the genus:—

'Carapace small and not hinged, produced anteriorly into a blunt snout, and posteriorly into rounded lobes. Body fusiform and long, composed of numerous segments which increase in length backwards, the seven posterior ones being uncovered by the carapace. Third segment from tail tumid and notched on its ventral surface. Telson long and spiniform, and flanked on each side by a rudimentary spinelet. Test smooth or slightly wrinkled, but not striated longitudinally.'

D. *Extra-British Fossil Phyllocarida.*

24. CERATIOCARIS (?) LONGICAUDA, D. Sharpe.

1853. *Dithyrocaris? longicauda*, D. Sharpe. 'Quart. Journ. Geol. Soc.' vol. ix. p. 158, pl. 7, fig. 3.

The ultimate segment and trifid appendage of a small Ceratiocarid of uncertain genus. Except that the central spine or style is the longest of the three, this little fossil might be almost matched with C. E. Beecher's *Elymocaris siliqua*, pl. 2, fig. 1, and p. 13, of his memoir in the 'Report Geol. Surv. Penns.' 1884. The segment (about 8 mm.) is described as 'simple and rounded'; the spines as 'lancet-shaped,' . . . 'the middle one somewhat rounded and twice as long as the lateral plates, which are nearly flat.' . . . 'From the upper division of the Lower Silurian formation at Sazes, in the Serra de Bussaco.' Collected by Senhor Carlos Ribeiro. In the Geological Society's Collection (?).

This set of spines is much stouter than the specimens M. P. G. D $\frac{22}{14}$, and both stouter and shorter than the somewhat similar small set in the Owens Coll. Mus. (See above, p. 350.)

25. CERATIOCARIS DEWEII, Hall.

1852. *Onchus Deweii*, J. Hall. 'Geol. Surv. New York, Palæontology,' vol. ii. p. 320, pl. 71, figs. 1*a*–1*d*.
1859. *Ceratiocaris Deweii*, J. Hall. 'Geol. Surv. N. Y. Pal.' vol. iii. p. 420*.

A fine large telson, 6 inches long, and about 20 mm. wide at its basal joint; gently curved, ridged, and pitted (once spinose); bulbous, with a strong articulation, at its base (figs. 1*a*, 1*b*). Figured with its sharp end upwards.

Also the ultimate segment (fig. 1*c*) of the abdomen, $2\frac{1}{2}$ inches (65 mm.) by about 22 mm. broad (high). Its ornament (fig. 1*d*) consists of imbricating, narrow, lanceolate, low elevations, which are obliquely striated, thus reminding us of the ornamentation of *C. Scharyi*, Barrande, 'Syst. Sil. Bohême,' p. 454, pl. 32, figs. 24–29; and we find similar ornamentation in some British forms.

C. Deweii is from the Niagara Shale (Upper Silurian) of Lockport and Rochester, State of New York.

26 & 27. CERATIOCARIS MACCOYIANA, J. Hall; and C. ACUMINATA, J. Hall.

1859. *Ceratiocaris Maccoyianus*, J. Hall. 'Geol. Surv. N. Y. Pal.' vol. iii. Part I. (text), p. 421*, and Part II. (plates), 1861, pl. 84, figs. 1–5.
1859. *C. acuminatus*, J. Hall. *L. c.* p. 417*, p. 422*, pl. 84, fig. 6, & 7 (?).

These specimens were obtained from the Upper-Silurian Waterlime Group, near Buffalo, New York State.

Fig. 1 (*C. Maccoyiana*) is rather obscure, and reminds us at first sight of an imperfect *C. stygia*, with the body-segments and caudal appendages reversed, so as to emerge from the anterior (broken) part of the carapace.

Fig. 2 has a carapace somewhat like *C. stygia*, modified by pressure, very delicately striate, and with the abdomen reversed to the anteroventral part of the carapace.

Fig. 3 shows two end segments and a trifid appendage, somewhat like those parts in a specimen (from Benson Knot), Cambr. Mus., *b*/6, which we refer with doubt to *C. stygia*.

Fig. 4 is a smaller and less perfect specimen.

Fig. 5 some segments and appendages much like those of some specimens of *C. stygia*.

Fig. 6 (*C. acuminata*) is an elegant carapace, ovately-trapeziform, slightly arched above, fully convex below, with a sloping, ogee, truncate posterior, and an acuminate front sloping rapidly down to the middle of the ventral margin, with its slope nearly parallel to that of the posterior truncation. It is finely striated longitudinally. This is very similar to some relatively narrow forms of *C. stygia*, particularly to Brit. Mus. '41898'; but still the details vary. It may also be compared with some forms of *C. Murchisoni*, such as M. P. G. x $\frac{1}{5}$ and x $\frac{1}{8}$, but not so satisfactorily.

Fig. 7 is a crushed portion of a large carapace, delicately striate on the ventral region, and four (?) crushed abdominal segments. Probably of the same species as fig. 6, as intimated by Prof. Hall (p. 417*).

28. Ceratiocaris aculeata, J. Hall.

1859. *C. aculeatus*, J. Hall. 'Geol. Surv. N. Y. Pal.' vol. iii. Part I. p. 422*; Part II. (plates), 1861, pl. 80 A, fig. 10.

This is apparently an ultimate segment (split), a broad telson (split ?), and one stylet. If so, the telson is 20 mm. long, and 5 mm. broad near its base, and is comparable with *C. robusta*. It is from the Waterlime Group, at Waterville, N. Y.

29. Ceratiocaris Nœtlingi, Fr. Schmidt.

1883. *Ceratiocaris Nötlingi*, Fr. Schmidt. 'Mém. Imp. Acad. Sci. St.-Pétersbourg,' ser. 7, vol. xxxi. p. 84, woodcut fig. 5; pl. 6, figs. 8, 9; pl. 7, fig. 12.

This has an elegant carapace (about 72 × 38 mm.), comparable with some individuals of our *C. Murchisoni* (Salter's '*leptodactylus*'), but not quite agreeing in all details. It is nearly semi-ovate in lateral outline, sharp in front, truncate with neat hollow curve behind. It closely approaches Dr. James Hall's *C. acuminatus*, which, however, is fuller in the ventral margin. The surface is delicately striated longitudinally, concentric with the ventral border; it is bordered ventrally with a thin raised rim.

A fine set of caudal spines (pl. 6, fig. 8) shows a telson (style) 38 mm. long, 11 mm. broad at its base, tapering rather rapidly, and ridged. The main ribs are tuberculate, and a blunt spine stands out on each side below the triangular bulb or base of the telson. One stylet (22 mm.) is rather broad, ensiform, and flat, except a faint median ridge. Fig. 9 is an imperfect style.

From an Upper-Silurian limestone, near Rootziküll, Oesel, in the Baltic.

30. M. Barrande's Species of Ceratiocaris.

The following *Ceratiocarides* have been carefully described and figured by the late M. J. Barrande; and we proceed to point out their most notable features, indicating characters by which they can be compared with the British and other forms.

(1.) Ceratiocaris docens, Barrande.

1856. *Leptonotus Bohemicus*, Barr. 'Parall. entre la Bohême et la Scandinavie,' p. 58.
1865. *Eurypterus*, sp. Barr. 'Défense des Colonies,' vol. iii. p. 235.

1868. *Eurypterus leptonotus*, Barr. Bigsby, 'Thes. Silur.' p. 199.
1872. *C. docens*, Barr. 'Syst. Sil. Bohême,' vol. i. Suppl. p. 450, pl. 21, figs. 32–35.

Seven segments, all somewhat displaced and those at the ends broken, about 80 mm. long altogether. Some are about 20 mm. high. Longitudinal ornament of delicate, interrupted, wrinkly, raised lines of two sizes (fig. 35). This belongs to Barrande's Silurian Stage[1] E e 2.

(2.) CERATIOCARIS DECIPIENS, Barrande.

1865. *Eurypterus*, sp. Barr. 'Déf. des Col.' vol. iii. p. 235.
1872. *C. decipiens*, Barr. 'S. S. B.' vol. i. Suppl. p. 449, pl. 21, figs. 36–38.

Three of the distal segments; the ultimate (longest) broken. Altogether about 35 mm. Much smaller than *C. docens*, stout-looking, subcylindrical or sub-quadrate in cross-section. The ornament is longitudinal, consisting of delicate, wrinkly, raised lines, in fascicules radiating backwards (upwards), fig. 38. This belongs to Stage E e 1. This fossil is so very similar to a *Bactropus* that it will probably be found to belong to one of the Phyllopods allied to *Aristozoe*. See further on, page 359.

(3.) CERATIOCARIS SCHARYI, Barrande.

1872. *C. Scharyi*, Barr. 'S. S. B.' vol. i. Suppl. p. 454, pl. 32, figs. 24–29.
1876. *C. Scharyi*, F. Rœm. 'Leth. geogn.' Th. i. 'Leth. pal.' Expl. pl. 19, fig. 6.

Seven segments (75 mm., ultimate segment 23 mm.). Height of the highest (sixth from the end), 20 mm.; height at the end of the ultimate segment, 10 mm. Proximal portion of the trifid appendage attached in place. Ornamented with a delicate imbrication of raised, leaf-shaped lines, like pointed arches, with a minute tracery of smaller leaf-like pattern within them: all pointing backwards (fig. 27). The same on the basal portion of the telson also. The ornament has some resemblance to the pattern on *Eurypterus*. It occurs also on *C. Deweii*, Hall, and on some British forms. This species belongs to Stage E e 1.

(4.) CERATIOCARIS BOHEMICA, Barrande.

1853. *Ceratiocaris* (*Leptocheles*) *Bohemicus*, Barr. 'Neues Jahrb. für Min.' &c. 1853. Heft iii. p. 342.
1868. *Ceratiocaris Bohemicus*, Barr. Bigsby, 'Thesaur. Silur.' p. 199.
1872. *C. Bohemicus*, Barr. 'Syst. Sil. Bohême,' vol. i. Suppl. p. 447, pl. 19, figs. 1–13.

Ultimate segment (fig. 1), 50 mm. long; with linear longitudinal ornament of interrupted raised lines. Telson ridged, and pitted (= spinose) along two channels on the back; linear ornament (as above) on the base; fragment 130 mm. Stylets (one perfect, 80 mm.), ridged.

Near to *C. Murchisoni*. Several specimens of telsons and stylets are in the Brit. Mus., some marked '44378,' '44428,' and '44383,' and some not numbered. This species belongs to Barrande's Stage E e 2.

[1] Barrande's 'Stages' are—

Third Fauna.—	Stages	H, h 1, 2 G, g 1, 2, 3, 4 F, f 1, 2 E, e 1, 2	= Passage-beds, Ludlow, Wenlock, and Llandovery.
Second Fauna.—	Stages	D, d 1, 2, 3, 4, 5	= Bala-Caradoc, Llandeilo, Lingula-flags, and Menevian.
Primordial Fauna.—	Stages	C, c 1	
Azoic		B A	= Precambrian, &c.

(5.) CERATIOCARIS INÆQUALIS, Barrande.

1868. *Ceratiocaris inæqualis*, Barr. Bigsby, 'Thes. Sil.' p. 199.
1872. „ „ „ 'Syst. Sil. B.' vol. i. Suppl. p. 452, pl. 19, figs. 14–16, 18; and Var. *decurtata*, figs. 17, 19.

Some segments and appendages. Much smaller than *C. Bohemica*. Telson 70 mm. long. Stylets (fig. 18), 30 mm. long; var. *decurtata* has them much shorter. A small crushed individual of this variety (fig. 19) bears the original little prickles along the telson. The lines of the longitudinal ornament are more inosculant than in *C. Bohemica* (fig. 15), and are oblique on a separate segment (fig. 16). The Brit. Mus. has two specimens ('42585'). This species belongs to Barrande's Colony d 5, and Stage E e 1, e 2. The var. to E e 1.

(6.) CERATIOCARIS ?[1] DEBILIS, Barrande.

1868. *Ceratiocaris debilis*, Barr. Bigsby, 'Thes. Sil.' p. 199.
1872. „ „ „ 'Syst. S. B.' vol. i. Suppl. p. 448, pl. 18, figs. 20–25; pl. 19, figs. 20–27; pl. 26, fig. 18; pl. 31, figs. 16–19.

Small, but like *C. Bohemica* in some respects. Only the appendages known. Style subflexuous (50 mm.), smooth on one (inner) face and pitted (= spinose) along two lines on the other (fig. 20). Style and stylets all ridged. A rostrum, probably of this species, narrow, chevron-marked, thin, and 6 mm. long, is shown at pl. 26, fig. 18. Ornamental lines, longitudinal, on the basal end of the telson (pl. 18, fig. 24). The Brit. Mus. has two pieces marked '42586,' in one of which some fragments of a style or stylet (marked *C. debilis*) lie close by a carapace of *Aristozoe perlonga*, Barrande. This species belongs to Barrande's Stage F f 2; *A. perlonga* also belongs to Stage F f 2.

(7.) CERATIOCARIS TARDA, Barrande.

1868. *Ceratiocaris tardus*, Barr. Bigsby, 'Thes. Sil.' p. 199.
1872. „ „ „ 'Syst. S. B.' vol. i. Suppl. p. 455, pl. 18, figs. 26–29.

Fragments of a style or stylet (?) Outer face rounded and smooth; inside channelled on each side of the smoothed and raised middle, with a row of large and small pits (= spines), symmetrically arranged in each channel (fig. 27). This species belongs to Stage G g 1.

(8.) CERATIOCARIS PRIMULA, Barrande.

1868. *Ceratiocaris primulus, imperfectus, et elegans*, Barr. Bigsby, 'Thes. Sil.' p. 199.
1872. „ „ Barr. 'Syst. S. B.' vol. i. Suppl. p. 453, pl. 18, figs. 14–19.

Two styles or stylets (?) only of this interesting form. They are spiniform, curved, and lozenge-shaped in section—that is, having four sloping sides or faces; the front and back edges are sharper than the side edges. The surface is faintly and irregularly ridged, and is pitted all over with the marks of former minute tubercles or spines (figs. 17 and 19). This belongs to Stage D d 5.

M. Barrande has described and figured several specimens of the dentate jaws (or teeth) like those of *Ceratiocaris* and *Dithyrocaris*, at p. 443, pl. 18, figs. 2–5; pl. 21, figs. 41–44; and pl. 31, fig. 21.

It is remarkable that no *Ceratiocaris* is represented by the *carapace* among M. Barrande's very numerous specimens. Some of the more

[1] See further on, p. 359, for O. Novák's remarks on this form in relation to *Bactropus* and *Aristozoe*.

unusual forms of telsons, such as *C. tarda* and *C. primula*, may belong to *Nothozoe* or some of the associated genera. M. O. Novák refers individuals of *C. debilis* to *Aristozoe regina* (see further on). Some also of the toothed mandibles may belong to such genera, as shown by Mr. C. E. Beecher.

31. M. BARRANDE'S ARISTOZOE, OROZOE, CALLIZOE, AND NOTHOZOE.

In 1863 ('Sixteenth Report State Cabinet N. Y.' p. 74) Dr. James Hall referred a certain Devonian Ceratiocarid, with some doubt, to *Aristozoe*, thus intimating a relationship for this genus different to that which Barrande thought of. Hall's species, however, has been since placed in the genus *Echinocaris* by Prof. R. P. Whitfield, who, though he did not regard *Aristozoe* as a Ceratiocaridal Phyllopod, but, with Barrande, as an Ostracod, collocated his *Aristozoe Canadensis* with some species of *Echinocaris* for comparison, in the plate (separate) illustrating his paper in the 'Americ. Journ. Sci.' ser. 3, vol. xix. January 1880. With these facts before us, as supporting our own views on the subject, we inserted the *Aristozoe*, *Orozoe*, and *Callizoe* of Barrande in our *Synopsis of the Genera of Fossil Phyllopods* at p. 217 of 'Brit. Assoc. Rep.' for 1883; and we now add his *Nothozoe* as being probably near to *Ceratiocaris*.

M. Barrande illustrated several species of these genera in his 'Système Silur. Bohême,' vol. i. Suppl. 1872. Some he had already mentioned by name in Dr. Bigsby's 'Thesaur. Siluricus,' 1868, p. 199. The genera were established in 1872.

1. *Aristozoe amica*, 1868, p. 476, pl. 24, figs. 32–39.
   „ *bisulcata*, 1868, p. 477, pl. 23, figs. 9–14.
   „ *inclyta*, 1872, p. 478, pl. 24, figs. 40, 41.
   „ *lepida*, 1872, p. 479, pl. 24, fig. 42; pl. 27, fig. 7; pl. 32, figs. 14, 15.
   „ *memoranda*, 1868, p. 480, pl. 24, figs. 43–51; pl. 27, fig. 6; pl. 32, figs. 16, 17.
   „ *orphana*, 1868, p. 481, pl. 23, figs. 6–8.
   „ *perlonga*, 1868, p. 482, pl. 23, figs. 26–39.
   „ *regina*, 1868, p. 483, pl. 22, figs. 14–23; pl. 27, fig. 5.
   „ (?) *Jonesi*, 1872, p. 478, pl. 25, figs. 9–13.
2. *Orozoe mira*, 1868, p. 537, pl. 24, figs. 23–26; pl. 31, figs. 7–9.
3. *Callizoe Bohemica*, 1868, p. 503, pl. 22, figs. 1–13.
4. *Nothozoe pollens*, 1868, p. 536, pl. 23, figs. 15–21; pl. 27, figs. 1–4.

1. *Aristozoe* has strong convex valves, straight dorsally, variously and often boldly curved downwards and backwards ventrally, with strong ventral rim. Various and usually strong cephalothoracic nodes, comprising tubercles which, marking places of attachment of internal organs, especially those of the buccal region, are usually present. The valves gape; in *A. Jonesi* (which has one feeble node) very widely at both ends. This, probably, is generically distinct. Valves of different species, and of different ages, vary from 10 to 80 mm. in length. The ornament in some is a minute reticulation (fig. 2, pl. 23); in others it is delicately linear (fig. 7*b*, pl. 27).

A. perlonga has persistently a small neat tubercle on the middle of the rim bordering the posterior edge of the valve. The tubercle of the muscle-spot (?) is very strong in this form, and the valves are relatively long and narrow. With one specimen of *A. perlonga* in the British Museum ('42586') a fragment of a thin caudal spine of some Ceratiocarid is closely imbedded. M. O. Novák has found reason to treat of *A. regina* as a Ceratiocarid with abdominal segments and caudal spines. (See further on.)

2. *Orozoe* has the cephalothoracic nodes very strong, and a great blunt spine projecting from the upper part of the posterior moiety of the valve.

3. *Callizoe* is very distinct from the foregoing. It is delicately shaped, long-half-egg-shaped, with straight back, and sometimes a slight inflection of the antero-ventral margin, near which the cephalothoracic nodes are placed, instead of dorsally as in *Aristozoe* and *Orozoe*. The ventral rim distinct and regular; the ornament of the valves delicate, longitudinal, inosculating, raised lines, with an intermediate minute punctation (fig. 7).

4. Barrande's *Nothozoe* is illustrated by seven figures of specimens, mostly ovate or oval, with plain surface; somewhat like *Ceratiocaris*, especially fig. 1, pl. 27. The ventral rim, however, is apparently too strong for that genus in figs. 1 and 2. The specimens measure 28 × 16, 40 × 25, 50 × 30, and 65 × 40 mm.

32. Aristozoe regina, Barrande, *and its abdominal appendages.*

M. Ottomar Novák, the keeper of the Barrande Collection at Prague, has lately made some valuable observations on some of the specimens collected by M. Barrande and referred by him to *Aristozoe*, *Bactropus*, and *Ceratiocaris debilis*. ('Remarques sur le genre *Aristozoe*, Barrande.' 'Sitzungsb. k. böhm. Gesellsch. Wissensch.' 1885.)

M. O. Novák has with great acumen discovered that such a telson as is described for *Ceratiocaris debilis* by Barrande will accurately fit, in all respects, the distal end of one of the fossil abdominal segments, figured and named *Bactropus longipes* by Barrande ('Sil. Syst. Bohême,' vol. i. Suppl. 1872, p. 581, pl. 21, figs. 1–22). Further, he has found that large numbers of individuals of the *Bactropus*, the Ceratiocarid telson, and *Aristozoe regina*, Barr., are associated in the same white limestone of the 'f 2' band over a wide area in Bohemia. Hence he has reason to regard the carapace, the abdominal segment, and the telson as all belonging to one animal. This seems, indeed, to be very likely; but at the same time there are probably more than one species and genus indicated by the telsons referred to *C. debilis*. One, at least (pl. 18, fig. 24), if correctly determined, has a longitudinal linear ornament, not agreeing with that of *Bactropus longipes*, which is transverse (pl. 21, fig. 22; and Novák, *op. cit.* pl. 1, figs. 21–23). M. Barrande found also a characteristic Ceratiocarid 'rostrum' with his *C. debilis* (pl. 26, fig. 18). M. Novák indicates that the structure of the basal joint of the telson would accommodate the hingement of two lateral stylets, so that *Aristozoe* would have had the trifid caudal appendage usual in the *Phyllocarida*. It yet remains to be shown how many were the abdominal segments of which the curious, cylindrical, tubular *Bactropus* was one, and what proportion this long ultimate segment bore to the others. M. Novák refers to it as 'a part of the post-abdomen (several segments? coalesced)'; further research will probably help in its elucidation.

33. Echinocaris and its Allies.

In the 'Geological Magazine,' dec. 3, vol. i. 1884, pp. 393–396, we published some 'Notes on Phyllopodiform Crustaceans referable to the Genus Echinocaris from the Palæozoic Rocks.' In this we mentioned in detail the evidence supplied by the labours of Dr. James Hall and Prof.

R. P. Whitfield for the genus *Echinocaris* and its species, and reproduced illustrative figures from their memoirs, namely:—

'Sixteenth Annual Report State Cab. N. Y.' 1863.

Ceratiocaris armatus, J. Hall, p. 72, pl. 1, figs. 1–3. Hamilton Group, Ontario County, N. Y.

„ *longicaudus*, J. Hall, p. 73, pl. 1, figs. 4–7 (?). Genessee Slate, Ontario County, N. Y.

„ ? *punctatus*, J. Hall, p. 74, pl. 1, fig. 8. Hamilton Group, Cayuga Lake, N. Y.

'Palæont. New York,' vol. v. part 2; 'Illustrations of Devonian Fossils,' &c. 1876.

Ceratiocaris armatus, J. Hall, pl. 23, figs. 4, 5.

„ *punctatus*, J. Hall, pl. 23, fig. 7.

Both of these are referred to one species in the Explanation of the Plate.

'Americ. Journ. Sci.' ser. 3, vol. xix. Jan. 1880.

Echinocaris sublevis, Whitfield, p. 36, figs. 4–6.

„ *pustulosa*, Whitfield, p. 38, fig. 7.

„ *multinodosa*, Whitfield, p. 38, fig. 8.

In separate plate. All from the Erie Shales (Portage and Chemung, at Leroy, Lake County, Ohio).

Echinocaris punctata, Hall. Whitf. p. 37. Carapace.
„ *armata*, Hall. Whitf. p. 37. Abdomen and telson.
} = *E. punctata*, according to Prof. Whitfield.

These two we put together as *E. armata*, 'Geol. Mag.' 1884, p. 393; and we hazarded the opinion that figs. 4, 5, and 6 of pl. 1 (1863) may have belonged to this species, and that certainly fig. 7 was specifically (if not generically) distinct.

Mr. C. E. Beecher, of Albany, has added considerably of late to our knowledge of *Echinocaris* and its allies ('Second Geol. Surv. Pennsylvania: Report of Progress, P.P.P.' 1884). Giving a careful account of the generic characters of this form, and of the specific features of *E. punctata* (Hall), p. 6, pl. 1, figs. 13–16, he adds *E. socialis*, n. sp., p. 10, pl. 1, figs. 1–12; and then describes *Elymocaris siliqua*, nov. gen. et sp., p. 13, pl. 2, figs. 1, 2; *Tropidocaris*, gen. nov., p. 15; *Tr. bicarinata*, n. sp., p. 16, pl. 2, figs. 3–5; *Tr. interrupta*, n. sp., p. 18, pl. 2, fig. 6; and *Tr. alternata*, n. sp., p. 19, pl. 2, figs. 7, 8. Except *E. alternata*, which is from the Waverley Group, the new species are from the Chemung Group, Warren, Pennsylvania. The trifid caudal appendage seems to have had the lateral spines (stylets) of nearly the same length as the central spine (telson or style). He describes also and figures some denticulated mandibles from the Hamilton Group, New York, at p. 9, and pl. 2, figs. 9–11.

We further added a critical note on the *Equisetides Wrightiana*, Dawson, from the Portage Group, New York State, 'Quart. Journ. Geol. Soc.' vol. xxxvii. 1881, p. 301, pl. 12, fig. 10, and pl. 13, fig. 20. We ventured to think we had good proof of this being really a portion of the abdomen (two segments) of a very large *Echinocaris*—*E. Wrightiana* (Dawson). Like the other *Echinocarides*, it was found in the Devonian strata of North America. This interesting relic represents perhaps the largest Ceratiocarid known, each segment being about 2 inches long, 2 inches high, and 1 inch thick.

With *E. armata* (*punctata*) Mr. Beecher finds associated many denticulated mandibles, similar to those found with *Ceratiocaris* in Scotland. Some he refers to that species; others he thinks belonged to an unknown species. Fig. 16 illustrates a pair of mandibles in place, 'nearly one-third the length of the valves'! The carapace of this species measures about 30 × 20 mm. (largest 55 × 37 mm.); there are six external segments, prickly on the back, smooth underneath, 35 mm.; telson, 23 mm.

E. socialis is a very small form, belonging to the same group as Whitfield's species from New York State. It measures 18 × 10 mm.; abdomen, 6 mm.; telson, 6 mm.

Elymocaris has its valves plainer and more oblong than those of *Echinocaris*. The long straight dorsal edge and elliptically curved ventral (deeper behind than in front) give a semi-ovate outline. The posterior is truncate, with a hollow curve just below the postero-dorsal angle. Ocular tubercle distinct, but the other cephalothoracic nodes are less developed than in *Echinocaris*, and occupy the angular anterior third of the valve. The abdomen preserved in fig. 1, pl. 2, shows a penultimate and an ultimate segment (the latter apparently split longitudinally), and a trifid appendage of a stout short telson and two stylets almost as broad and quite as long, 'crenulated along their inner margins for the attachment of fimbria,' as in *Dithyrocaris Neptuni*, Hall, and *D. tricornis*, Scouler. This set of stout small caudal spines and segments will doubtless prove very useful in comparing other but less distinct fossil appendages.

Carapace-valve, 23 × 10 mm.; two segments, 10 mm.; telson, 9 mm.

Tropidocaris has semielliptical valves (25 × 12 mm. and 37 × 14 mm.), very similar in outline to those of *Elymocaris*, but ornamented with 2–7 longitudinal, interrupted, raised, parallel ridges (somewhat analogous to those on some varieties of *Kirkbya permiana* and *K. euglypha*, but more especially to those on some of the species of *Dithyrocaris*). Delicate curved striæ also on some valves. Optic and other nodes present. Abdominal segments small, cylindrical, tapering, not well known.

34. The COLPOCARIS of F. B. Meek is a Carboniferous fossil of much interest, though of doubtful character in some respects.

1868. *Ceratiocaris? sinuatus*, Meek and Worthen. 'Amer. Journ. Sci.' vol. xlvi. p. 22.
1873. *Ceratiocaris? sinuatus*, M. and W. 'Geol. Surv. Illinois' (Geol. and Palæont.), p. 540, fig. 5, woodcut.

Somewhat rhombic-subovate; posterior end truncate and deeply sinuous; dorsal margin a depressed arch. From the Coal-measures, Grundy County, Illinois.

1872. *Colpocaris* (? sub-genus of *Ceratiocaris*) *Bradleyi* and *elytroides*, Meek. 'Proceed. Acad. Nat. Sci. Philada.' vol. xxiv. pp. 332–34.
1875. *Ceratiocaris* (*Colpocaris*) *Bradleyi*, Meek. 'Report Geol. Surv. Ohio,' vol. ii. (Geol. and Palæont.), Part II. 'Palæontology,' p. 318, pl. 18, figs. 6*a*–6*e*.
1875. *Ceratiocaris* (*Colpocaris*) *elytroides*, Meek. *Op. cit.* p. 319, pl. 18, figs. 5*a*, 5*b*.

These are acute-oval, but one end has a relatively large semicircular notch cut into it. The first of these two differs but little, except in the relative depth and slight obliquity of semicircular notch in what is described as the posterior margin. The surface is minutely reticulate (fig. 6*c*). A large and a small individual are figured; 70 × 32 mm., and 24 × 10 mm. Fig. 6*d* indicates a set of three caudal spines, and 6*e*, another set not so perfect. These were found associated with the carapace-valves. Figs. 5*a*, 5*b*, is a small species (28 × 13 mm.) of a generally similar outline; and fig. 5*c* shows its longitudinal linear ornament. These are from the Carboniferous beds of Ohio, U.S. As yet we have no knowledge as to the exact relationship of *Colpocaris*. See also Prof. Whitfield's remarks, 'Americ. Journ. Sci.' vol. xix. 1880, p. 36.

The other Phyllopodous genera mentioned in our lists, such as *Dithyrocaris*, *Estheria*, &c., will be treated of at another opportunity.

Fifth Report of the Committee, consisting of Mr. R. ETHERIDGE, Mr. THOMAS GRAY, *and* Professor JOHN MILNE (*Secretary*), *appointed for the purpose of investigating the Earthquake Phenomena of Japan.* (*Drawn up by the Secretary.*)

ON account of an excursion which I have the intention of making during the coming summer to Australia and New Zealand I am compelled to draw up this report a month earlier than usual. As the only time when the work of attending to observations and experiments repays itself is during the winter months, I may safely say that my intention of shortening the time usually devoted to earthquake observations is not likely to involve any serious loss.

If we refer to the records of the last year—that is to say, from the end of April 1884 to the end of April 1885—it will be seen that the opportunities for making observations have been unusually good. The number of earthquakes felt during corresponding periods in two previous years and this last year was respectively twenty-six, thirty-nine, and eighty.

Not only have the earthquakes been numerous, but some of them have been pretty stiff, as is testified by the fact that on several occasions chimneys fell and walls were cracked.

The work done during the last year is briefly as follows.

Seismic Experiments.

From time to time I have had the honour of reporting to the British Association on seismic experiments. These experiments were commenced in conjunction with Mr. T. Gray in 1880. The movements which were then recorded were produced by allowing a heavy ball, 1,710 lbs. in weight, to fall from various heights up to thirty-five feet. Subsequently many experiments were made by exploding charges of dynamite and gunpowder placed in bore-holes. The observations which were made upon the resultant vibrations of the ground were very numerous. As examples of them may be mentioned—the determination of the nature of earth vibrations as deduced from diagrams, the velocity of propagation of different kinds of vibrations, the relative motion of neighbouring points of ground, experiments on the production of earth currents, experiments on projection and overturning, &c.

During the last year, whilst working up the long series of records which accumulated, several laboratory experiments were made to investigate the methods to be employed when analysing the diagrams of earth motion.

The first of these experiments consisted in projecting a small ball from the top of a tall flat vertically-placed spring, and at the same time causing the spring to draw a diagram of its motion. From the distance the ball was thrown its initial velocity could be calculated. From the diagram, either by calculation on the assumption of simple harmonic motion or by direct measurement, the maximum velocity of movement could be obtained.

These three quantities practically agreed. The most important result obtained by these experiments was that they indicated an important element to be calculated in earthquake or dynamite diagrams, and, further

that in these diagrams the first sudden movement, which invariably has the appearance of a quarter-oscillation, ought apparently to be considered as a semi-oscillation.

The second set of experiments consisted in determining the quantity to be calculated from an earthquake diagram which would give a measure of the overturning or shattering power of a disturbance.

For this purpose a light strip of wood was caused by means of a strong spiral spring and a heavy weight to move horizontally back and forth with the period of the spring. On this strip small columns of wood were stood on end, and it was determined how far the spring had to be deflected and then suddenly released to cause overturning.

Knowing the period of the spring and its amplitude, the maximum velocity v, the meantime acceleration $\frac{v}{t}$, and the maximum acceleration $\frac{v^2}{a}$ might be calculated. An acceleration, f, sufficient to cause overturning could also be calculated from the dimensions of the column. The result of various experiments showed that for small deflections f was nearly equal to $\frac{v}{t}$, but for larger deflections the value for f lies between $\frac{v}{t}$ and $\frac{v^2}{a}$. From this it seems that the overturning power of an earthquake can only be approximately determined from the dimensions of a body which has been overthrown. The quantity f is not the quantity v, or 'maximum velocity of an earth particle,' so largely employed by Mallet and other earthquake investigators. Such a quantity, which may be determined for bodies of definite dimensions on the assumption that they are overturned by a *sudden blow*, so far as my experiments have gone, does not tell us anything about the nature of earthquake motion.

An account of these and other experiments which I have from time to time been engaged upon will shortly be published as a part of Vol. VIII. in the 'Transactions of the Seismological Society.' The more important results of all these experiments are as follows.

In reading these conclusions it must be remembered that they only refer to experiments performed in certain kinds of ground.

I. *Effect of Ground on Vibration.*

1. Hills have but little effect in stopping vibrations.
2. Excavations exert considerable influence in stopping vibrations.
3. In soft damp ground it is easy to produce vibrations of large amplitude and considerable duration.
4. In loose dry ground an explosion of dynamite yields a disturbance of large amplitude but of short duration.
5. In soft rock it is difficult to produce a disturbance the amplitude of which is sufficiently great to be recorded on an ordinary seismograph.

II. *General Character of Motion.*

1. The pointer of a seismograph with a single index first moves in a normal direction, after which it is suddenly deflected, and the resulting diagram yields a figure partially dependent on the relative phases of the normal and transverse motion. These phases are in turn dependent upon the distance of the seismograph from the origin.

2. A bracket seismograph indicating normal motion at a given station commences its indications before a similar seismograph arranged to write transverse motion.

3. If the diagrams yielded by two such seismographs be compounded, they yield figures containing loops and other irregularities not unlike the figures yielded by the seismograph with the single index.

4. Near to an origin, the first movement will be in a straight line outwards from the origin; subsequently the motion may be elliptical, like a figure 8, and irregular. The general direction of motion is, however, normal.

5. Two points of ground only a few feet apart may not synchronise in their motions.

6. Earthquake motion is probably not a simple harmonic motion.

III. *Normal Motion.*

1. Near to an origin the first motion is outwards. At a distance from an origin the first motion may be inwards.

As to whether it will be inwards or outwards is probably partly dependent on the intensity of the initial disturbance, and on the distance of the observing station from the origin.

2. At stations near the origin the motion inwards is greater than the motion outwards. At a distance the inwards and outwards motion are practically equal.

3. At a station near the origin, the second or third wave is usually the largest, after which the motion dies down very rapidly in its amplitude, the motion inwards decreasing more rapidly than the motion outwards.

4. Roughly speaking, the amplitude of normal motion is inversely as the distance from the origin.

5. At a station near an origin the period of the waves is at first short. It becomes longer as the disturbance dies out.

6. The semi-oscillations inwards are described more rapidly than those outwards.

7. As a disturbance radiates the period increases. Finally it becomes equal to the period of the transverse motion. From this it may be inferred that the greater the initial disturbance the greater the frequency of waves.

8. Certain of the inward motions of 'shock' have the appearance of having been described in less than no time.

9. Tables have been calculated to show the maximum velocity of normal motion.

10. Diagrams have been drawn to show the intensity of normal motion.

11. The first outwards motion, which on diagrams has the appearance of a quarter-wave, must be regarded as a semi-oscillation.

12. The waves on the diagrams taken at different stations do not correspond.

13. At a station near the origin, a notch in the crest of a wave of shock gradually increases as the disturbance spreads, so that at a second station the wave with a notch has split up into two waves.

14. Near the origin the normal motion has a definite commencement. At a distance the motion commences irregularly, the maximum motion being reached gradually.

IV. *Transverse Motion.*

1. Near to an origin the transverse motion commences definitely but irregularly.

2. Like the normal motion, the first two or three movements are decided, and their amplitude slightly exceeds that of those which follow.

3. The amplitude of transverse motion as the disturbance radiates decreases at a slower rate than that of the normal motion.

4. As a disturbance dies out at any particular station the period decreases.

5. As a disturbance radiates the period increases. This is equivalent to an increase in period as the intensity of the initial disturbance increases.

6. As we recede from an origin the commencement of the transverse motion becomes more indefinite.

7. It will be observed that the laws governing the transverse motion are practically identical with those which govern the normal motion, the only difference being that in the case of normal motion they are more clearly pronounced.

V. *Relation of Normal to Transverse Motion.*

1. Near to an origin the amplitude of normal motion is much greater than that of the transverse motion.

2. As the disturbance radiates, the amplitude of the transverse motion decreases at a slower rate than that of the normal motion, so that at a certain distance they may be equal to each other.

3. Near to an origin the period of the transverse motion may be double that of the normal motion; but as the disturbance dies out at any given station, or as it radiates, the periods of these two sets of vibrations approach each other.

VI. *Maximum Velocity and Intensity of Movement.*

1. An earth particle usually reaches its maximum velocity during the first inward movement. A high velocity is, however, sometimes attained in the first outward semi-oscillation.

2. The intensity of an earthquake is best measured by its destructive power in overturning, shattering, or projecting various bodies.

3. The value $v^2 = \frac{4}{3} g \sqrt{a^2 + b^2} \times \left(\frac{1 - \cos\theta}{\cos^2\theta} \right)$ used by Mallet and other seismologists to express the velocity of shock as determined from the dimensions of a body which has been overturned, is a quantity not obtainable from an earthquake diagram. It represents the effect of a sudden impulse.

4. In an earthquake a body is overturned or shattered by an acceleration, f, which quantity is calculable for a body of definite dimensions.

The quantity f as obtained from an earthquake diagram lies between $\frac{v}{t}$ and $\frac{v^2}{a}$, where v is the maximum velocity, t is the quarter-period, and a is the amplitude.

5. The initial velocity given in the formula $v^2 = \frac{2\ a^2}{b}$ (for horizontal projection), used by Mallet as identical with v^2 in 3, is not an identical quantity.

The velocity calculated from the range of projection when projection occurs is identical with the maximum velocity as measured directly or calculated from a diagram.

6. In discussing the intensity of movement I have used the values $\frac{v^2}{a}$.

7. The intensity of an earthquake at first decreases rapidly as the disturbance radiates; subsequently it decreases more slowly.

8. A curve of intensities deduced from observations at a sufficient number of stations would furnish the means of approximately calculating an absolute value for the intensity of an earthquake.

VII. *Vertical Motion.*

1. In soft ground vertical motion appears to be a free surface wave which outraces the horizontal component of motion.

2. Vertical motion commences with small rapid vibrations, and ends with vibrations which are long and slow.

3. High velocities of transit may be obtained by the observation of this component of motion. It is possibly an explanation of the preliminary tremors of an earthquake and the sound phenomenon.

4. The amplitude and period of vertical waves as observed at the same or different stations have been measured.

VIII. *Velocity.*

1. The velocity of transit decreases as a disturbance radiates.

2. Near to an origin the velocity of transit varies with the intensity of the initial disturbance.

3. In different kinds of ground, with different intensities of initial disturbance, and with different systems of observation, I determined velocities lying between 630 and about 200 feet per second. Mallet determined a velocity in sand of 824 feet, and in granite of 1,664 feet, per second. General Abbot has observed velocities of 8,800 feet per second. All of these determinations I regard as being practically correct, the great difference between them being due partly to the nature of the rock, the intensity of the initial disturbance, and the kind of wave which was observed.

4. In my experiments the vertical free surface wave had the quickest rate of transit, the normal being next, and the transverse motion being the slowest.

5. The rate at which the normal motion outraces the transverse motion is not constant.

6. As the amplitude and period of the normal motion approach in value to those of the transverse motion, so do the velocities of transit of these motions approach each other.

7. By cross-bending and torsion of cylinders of rocks the velocity with which normal and transverse vibrations would be propagated in such rocks has been determined. These determinations show that the

ratio of the speed of these two kinds of motion is not constant. The softer and less elastic rocks are, the nearer do these velocities approach each other. That the ratio of the speed of normal and transverse motions is not constant is shown from a table of these velocities calculated for different rocks from their moduli of elasticity.

IX. *Miscellaneous.*

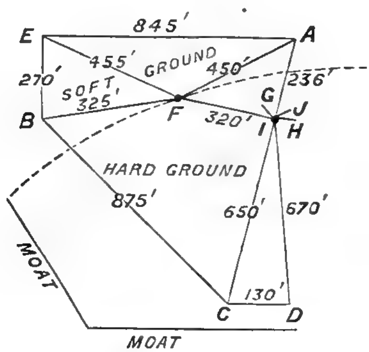
1. At the time of an earth disturbance, currents are produced in telegraph lines.
2. The exceedingly rapid decrease in the intensity of a disturbance in the immediate neighbourhood of the epicentrum has been illustrated by a diagram.
3. For the duration of a disturbance due to a given impulse in different kinds of ground, reference must be made to the detailed descriptions of the first four sets of experiments.

X. *The Simultaneous Observation of Earthquakes at several Stations in Electrical Connection.*

In my last report to the Association I gave the results of observations carried on at three stations, which were indicated by the numerals I., II., and III. These three stations I now call A, B, and C, and have added on to them other stations in the same area called D, E, F, G, H, and J.

G refers to the records taken by an instrument placed inside a house specially constructed to mitigate the effects of earthquake motion. H is a station in a pit 10 feet deep. To these records I shall make special reference. J is a station where there are now two instruments. It is between the house and the pit, about 20 or 30 feet from each. F is a station on the edge of flat marshy ground, at the foot of a slope running nearly north and south. At a level of about 10 feet above this are the stations C and D on hard ground. The relative position of these stations will be understood from the following sketch (fig. 1). A line from A to

Fig. 1.



B bears S 15° 30′ W. The dotted line shows a gentle slope dividing the soft ground from the hard ground. The softest ground is in the middle of the triangle B, E, F, where it is quite marshy. The following five tables embody the principal results which have been obtained. For stations G, H, and J the number of observations are too few to give average results. I is the starting station.

Number of Waves in Ten Seconds.

1884–85	A	B	C	D	E	F	G	H	J
March 25 . .	22	18							
" 31 . .	30	32	23						
April 6 . .	30	25	32						
May 6 . .	32	26	35						
" 11 . .	30	27	35						
" 19 . .	37	33	21						
" 19 . .	22	26							
" 30 . .	28	21							
" 31 . .	31	28							
June 11 . .	32	26		26					
October 24 . .	36	30							
November 16 .	34	32		38					
" 21 .	36	35		38					
" 27 .	36	28		38					
" 29 .	36	18		*					
December 7 .		34		†					
" 9 .	24			24					
" 16 .	30	28		40					
" 23 .		26							
" 30 .	32			42	30 or 16				
January 2 . .		26		26	40 or 12	40			
February 1 .	28	20							
" 4 .	30	30			24				
" 12 .	30	28			14	34	72‡		
" 27 .	32	32			36				
" 28 .					50				
March 12 . .	30	26			18		48		
" 20 . .	30	30			14			12	26
Average . .	30	28	29	34	23 or 28	37	60	12	26

Period of Largest Wave in Seconds.

1884–85	A	B	C	D	E	F	G	H	J
March 25 . .	·73	·85							
" 31 . .	·30	·24	·33						
April 6 . .	·36	·61	·36						
May 6 . .	·47	·70	·36						
" 11 . .	·35	·47	·26						
" 19 . .	·23	·36	·20						
" 19 . .	·40	·50							
" 30 . .	·36	·40							
" 31 . .	·35	·30							
June 11 . .	·36	·36		·36					
October 24 . .	·32	·41							
November 16 .	·47	·47		·23					
" 21 .	·27	·45		·30					
" 27 .	·45	·36		·20					
" 29 .	·36	·56		·40					
December 7 .		·24		·24					
" 9 .	·40			·40					

* At D too irregular to estimate. † At D too small to estimate. ‡ Ripples.

Period of Largest Wave in Seconds—continued.

1884–85	A	B	C	D	E	F	G	H	J
December 16 .	·45	·54		·37					
„ 23 .		·40							
„ 30 .	·32			·18	·75				
January 2 . .		·70		·18	·90	·18			
February 1 .	·45	·82			·50		·18		
„ 4 .	·21	·30							
„ 12 .	·39	·39			·72	·42	·39		
„ 27 .	·24	·28			·25				
„ 28 .					·18				
March 12 . .	·18	·29			·64		·31		
„ 20 . .	·44	·53			1·40			·85	·55
Average . .	·29	·46	·30	·28	·66	·30	·44	·85	·55

Maximum Amplitude in Millimetres.

1884–85	A	B	C	D	E	F	G	H	J
March 25 . .	·10	·50							
„ 31 . .	·10	·14	·05						
April 6 . .	·30	·80	·10						
May 6 . .	·40	·10	·10						
„ 11 . .	·30	·90	·10						
„ 19 . .	·07	·15	·04						
„ 19 . .	·10	·20	·02						
„ 30 . .	·05	·10							
„ 31 . .	·05	·10							
June 11 . .	·15	·25		·10					
October 24 . .	·07	·10							
November 16 .	·25	·30		·05					
„ 21 .	·10	·25		·05					
„ 27 .	·15	·25		·05					
„ 29 .	·20	·60		·05					
December 7 .	·10	·20		·05					
„ 9 .	·07			·05					
„ 16 .	·80	1·20		·25					
„ 23 .		·10							
„ 30 .	·45			·20	1·90				
January 2 . .		·25		·05	2·50	·05			
February 1 .	·05	·07			·10	·01	·05		
„ 4 .	·05	·10			·05	·02			
„ 12 .	1·20	·80			2·20	·70	·50		
„ 27 .	·10	·12			·05		·04		
„ 28 .					·05				
March 12 . .	·10	·30			·60		·10		
„ 20 . .	1·37	1·40			1·90			·035	1·2
Average . .	·37	·40	·07	·09	·95	·19	·17	·035	1·2

Maximum Velocity in Millimetres per Second.

1884–85	A	B	C	D	E	F	G	H	J
March 25 . .	·9	3·7							
„ 31 . .	2·1	3·6	·9						
April 6 . .	5·0	8·0	1·7						
May 6 . .	5·3	9·0	1·7						
„ 11 . .	6·0	12·0	2·4						
„ 19 . .	1·8	2·6	1·2						
„ 19 . .	1·5	2·5							
„ 30 . .	·9	1·5							
„ 31 . .	·8	2·0							
June 11 . .	2·7	4·5		1·80					
October 24 . .	1·3	1·5							
November 16 .	3·5	4·0		1·30					
„ 21 .	2·2	3·5		1·00					
„ 27 .	2·0	4·4		1·50					
„ 29 .	3·4	7·0		·78					
December 7 .		5·0		1·20					
„ 9 .	1·0			·70					
„ 16 .	11·0	14·0		4·20					
„ 23 .		1·5							
„ 30 .	9·0			7·00	16·0				
January 2 . .		2·2		1·70	17·0	1·7			
February 1 .	·7	·6			1·2				
„ 4 .	1·5	2·0							
„ 12 .	19·0	1·3			1·9	10·1	12		
„ 27 .	2·6	2·7			1·2				
„ 28 .					2·0				
March 12 . .	3·4	6·0			5·8		2		
„ 20 . .	18·0	16·0			8·0				
Average . .	4·4	5·3	1·6	1·40	9·7	5·7	7	·25	13

Maximum Acceleration in Millimetres per Second.—Intensity.

1884–85	A	B	C	D	E	F	G	H	J
March 25 . .		27							
„ 31 . .	44	92	16						
April 6 . .	83	80	28						
May 6 . .	70	81	28						
„ 11 . .	120	160	57						
„ 19 . .	46	45	38						
„ 19 . .	22	31							
„ 30 . .	16	22							
„ 31 . .	13	40							
June 11 . .	48	81		32					
October 24 . .	27	22							
November 16 .	49	53		34					
„ 21 .	48	49		20					
„ 27 .	27	77		45					
„ 29 .	57	81		12					
December 7 .		125		28					
„ 9 .	14			9					
„ 16 .	151	171		70					
„ 23 .		22							
„ 30 .	180			245 ?	135				
January 2 . .		19		58	116	58			
February 1 .	10	5			14		?		
„ 4 .	45	40							
„ 12 .	300	210			170	145	128		
„ 27 .	67	60			28				
„ 28 .					80				
March 12 . .	115	120			56		40		
„ 20 . .	249	182			34			1·7	140
Average . .	75	75	33	55	79	101	84	1·7	140

The analysis of the diagrams from which the above tables have been calculated has not yet been completed. Some of the more important results to which they point are as follows:—

1. All stations have invariably given different records for the same earthquake. The principal differences relate to direction, period, amplitude, maximum velocity, and maximum acceleration.

2. On the hard ground, as at C and D, the amount of motion is very much less than at the remaining stations, like A, B, F, and E. Comparing together the average maximum velocities and maximum accelerations at C and E, we see that they have respectively been as 1 to 5 and 1 to 2·4. A practical conclusion to be drawn from this is that a house at C might stand whilst a similar house at E might be shattered.

3. Similar waves only appear in the diagrams at different stations where an earthquake is strong.

4. As a disturbance passes from station to station the time interval between two similar waves suffers a change. This leads to uncertainty in determining the velocity with which a disturbance travels.

Other results to be derived from these observations will be given at a future period. In the tables of the report upon stations A, B, and C, published in 1884, several misprints occurred. These are now corrected.

Experiments on a Building to resist Earthquake Motion.

In the report of last year I described a house which rested at its foundations upon cast-iron balls. These balls were 10-inch shells. The records obtained from an instrument placed inside this house showed that, although it was subjected to considerable movement at the time of an earthquake, all *sudden* motion had been destroyed. Although the balls did very much to mitigate earthquake motion, wind and other causes produced movements of a far more serious nature than the earthquake. To give greater steadiness to the house, 8-inch balls were tried, and then 1-inch balls. Finally the house was rested at each of its piers upon a handful of cast-iron shot, each $\frac{1}{4}$ inch in diameter. By this means the building has been rendered astatic, and, in consequence of the great increase in rolling friction, sufficiently stable to resist all effects like those of wind. The shot rest between flat iron plates. That the house had peculiar foundations would not be noticed unless specially pointed out. The motion experienced in the house is indicated in column G of the preceding tables. The best idea of this motion is seen by reference to the accompanying diagram, taken on February 12, 1885. From this diagram it will be seen that in the house only two small shocks, A and B, were recorded, whilst at all the other stations, not only were there many shocks equivalent to A and B, but there were many which were greater. From these experiments it seems evident that it is possible to build light one-storied structures of wood or iron in which, relatively to other houses, but little movement will be felt.

Observations in a Pit 10 *feet deep.*

The instrument placed in this pit is similar to all the other instruments, and is installed in a similar position. Column H in the preceding tables refers to the observations which have been made. Comparing the

maximum amplitudes, maximum velocities, and maximum accelerations obtained in the pit with those obtained at about thirty feet distance at station J, they are for one particular earthquake respectively in the ratios of 1 : 43, 1 : 52, and 1 : 82 (see diagram for March 20, 1885).[1] In most earthquakes the extent of motion has been too small to admit of measurement, and that there had been any movement could only be detected by holding the plate on which the record was written up to the light and glancing along it lengthways. This investigation tends to confirm the view which I have previously put forward, that an earthquake at a short distance from its epicentrum is practically a surface disturbance, principally consisting of horizontal movements. The vertical motion is small, and is best seen in the preliminary tremors either of an actual earthquake or of a dynamite explosion. From a practical point of view these results must be of the greatest importance to those who have to erect heavy structures in earthquake districts. At a future time I hope to continue these experiments by comparing together the motion—1st, of a foundation unattached to the sides of the excavation where it is built; 2nd, of a similar foundation connected to the sides by brushwood and covered with a layer of earth; 3rd, of a similar foundation put in the ground in the ordinary method; 4th, of a piece of ground isolated with trenches; and 5th, of the ordinary ground.

Buildings in Earthquake Countries.

As during the last few years so much destruction both to life and property has taken place in various parts of Europe, it seems that an epitome of the results of observations and experiments carried on in Japan relative to construction in seismic districts might not only be interesting, but possibly it might also be of practical value. When erecting a building it appears that we ought first to reduce as far as possible the quantity of motion which ordinary buildings receive; and, second, to construct a building that it will resist that portion of the momentum which we are unable to keep out. To reduce the momentum which usually reaches a building the following may be done:—

1. Institute a seismic survey of the district or area in which it is intended to build, and select a site where experiment shows that the motion is relatively small.

2. For heavy buildings adopt deep foundations (perhaps with lateral freedom), or at least let the building be founded on the hardest and most solid ground. It is perhaps because the tops of the hills in Tokio are harder than the plains that they have relatively the least motion. To what extent a building may be isolated by trenches or natural valleys is not yet known, but it must be remembered that a building only *partially* isolated may be exceedingly dangerous from the fact that motion entering in the unprotected side will make the excavations (cuttings, valleys, &c.) upon the opposite side into free surfaces which will swing forward through a range greater than they would have swung had the excavations not existed.

3. For light buildings, especially if erected on soft ground, where the range of motion is always great, if the structure rests on layers of fine cast-iron shot, it cannot possibly receive the same momentum as a build-

[1] I am not yet prepared to state whether these ratios will hold for all earthquakes.

ing attached to the moving ground. The extent to which the acquisition of momentum may be avoided by the adoption of one or all of these methods may be judged of by reference to the three previous sections of this report. To resist the effects of momentum which cannot be cut off a building, and therefore tends to shatter it, the following rules appear to be among the most important:—

1. Bear in mind the fact that it is chiefly stresses and strains which are applied horizontally to a building which have to be encountered. Ordinary masonry arches are continually cracked by earthquakes, inasmuch as they are only designed to resist the stresses due to gravity. Iron or wooden lintels, or at least tie-rods, may be used to strengthen or replace such arches. Arches which meet these abutments at an angle are more liable to be cracked than those which meet them with a curve. A vertical line of openings like doors or windows in a building constitute a vertical line of weakness to horizontally-applied forces.

2. Avoid coupling together two portions of a building which have different vibrational periods, or which from their position are not likely to synchronise in their motion. If such parts of a building must of necessity be joined, let them be so joined that the connecting link will force them to vibrate as a whole, and yet resist fracture.

Brick chimneys in contact with the framing of a wooden roof are apt to be shorn off at the point where they pass through the roof. Light archways connecting heavy piers will be cracked at the crown. To obviate destruction due to these causes a system of construction similar to that to be seen in several of the buildings of San Francisco, Tokio, and Yokohama may be adopted. This essentially consists of tieing the building together at each floor with iron and steel tie-rods crossing each other from back to front and from side to side. In connection with this subject I may mention that experiments have shown that in strong earthquakes the abutments of heavy archways approach and recede from each other, cracks in buildings open and shut, other cracks grow longer, and finally that two points of ground not ten feet apart do not synchronise in their motion. These facts show that the assumption of a difference in vibrational phase in parts of a building shaken by an earthquake is not simply an assumption made to explain certain often-repeated observations.

3. Keep the centre of inertia of a building or its parts as low as possible. Heavy tops to chimneys, heavy copings, and balustrades on walls and towers, heavy roofs and the like are all sources of danger to the portion of the structure by which they are supported. When the lower part of a building is moved, the upper part by its inertia tending to remain behind often results in serious fractures. All the chimneys in Tokio and Yokohama which have fallen in consequence of their ornamental heads have been replaced by shorter and thicker chimneys without the usual coping. The roof of a portion of the Engineering College rests loosely on its walls, and has therefore a certain freedom. In Manila many heavy roofs have been replaced by roofs of sheet iron. Walls may be lightened in their upper parts by the use of hollow bricks. Such vertical motion as may exist is also partly obviated by light superstructures. Vertically-placed iron tie-rods give additional security.

If these and other rules which are the result of experiment and observation could be adopted in earthquake countries, it is certain that the loss of life and property might be greatly diminished. Before building

to withstand the effects of earthquake motion it is necessary that the constructor should clearly understand the nature of earthquake motion. If an earthquake is regarded as a sudden blow, and we adopt rules and formulæ founded on this supposition such as are to be found in many of the older treatises on this subject, it seems certain that the success of our undertakings must inevitably be attended with uncertainty.

Earth Tremors and Earth Pulsations.

From time to time reference has been made in reports to this Association to the various methods employed to record earth tremors and earth pulsations. Many of the observations made with delicate spirit levels have now been plotted. The most complete set were those made at the Meteorological Observatory under the direction of Mr. Arai Ikunosuke. The observations were made every three hours both night and day. Although a special column was built for the instalment of these levels, and they were protected so far as possible from changes in temperatures, the bubbles of these instruments wandered to and fro in a manner difficult to explain. M. d'Abbadie, writing to me on this subject, remarks that two levels may be placed parallel and yet the bubbles may move in opposite directions.

Notwithstanding the untrustworthiness of level observations, they nevertheless have given results of interest. These are as follows:—

1. The fact that the bubbles from time to time move back and forth without apparent reason. Considerable changes have sometimes been observed before an earthquake.

2. The greatest movement of the bubble of a level takes place during the colder part of the year, which is the season of earthquakes, and also the season when the barometric gradient between Siberia and the Pacific is the steepest.

3. The bubble of a level continues to move long after the sensible motion of an earthquake has ceased, enabling us to study the slow movements which bring an earthquake to a close.

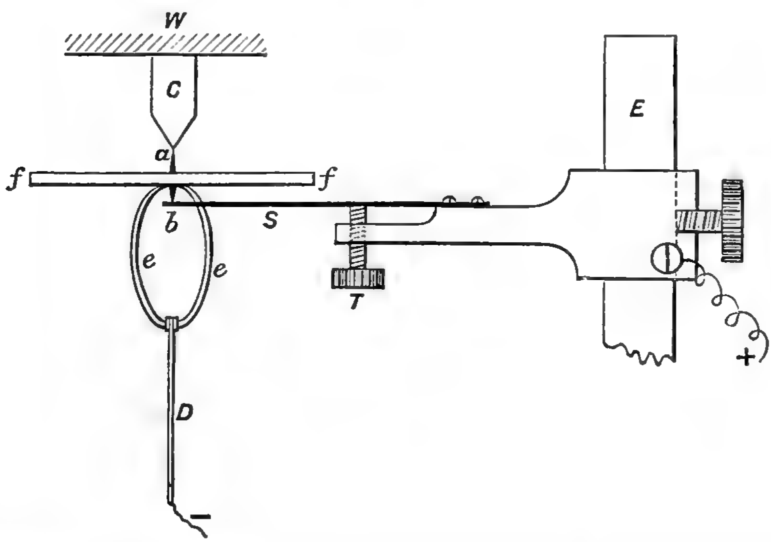
4. When the barometer is very low, as, for instance, during a typhoon, the bubble of a level may be distinctly seen to pulsate back and forth through a range of about ·5 mm.

In addition to the fact that levels are so sensitive to changes of temperature, they have, in common with all other instruments with which I am acquainted, the objections that their changes between the times of observation are unknown. For a long time I experimented to obtain an instrument which would give an automatic record of earth tremors and earth pulsations. After many failures I think that I have at last succeeded in obtaining such an instrument. It is simple, cheap, and exceedingly easy to manipulate. M. d'Abbadie tells me that it has many points in common with an instrument employed by M. Boquet de la Grye. It is briefly as follows. From a circular cast-iron bed plate resting on three levelling screws, there rises a tripod of angle iron about 5 feet high. From the top of this hangs a pendulum, consisting of a thin iron wire and a heavy bob. At the base of this bob, W, there is a small projection C (see fig. 2). As the bob and the projection were turned in a lathe, the extremity of C, which is flat, the centre of figure of the bob and the point where the supporting wire is attached are in one vertical line. Below this bob there is an indicating pointer, *a*, *b*, *c*, *d*, the full length of which is

not shown. *a* and *b* are needle points. The lower point *b* rests on a flat spring, S, which can be raised or lowered by the screw T connected with a solid stand E. By raising *b* the point *a* is brought into contact with the end of C. *f f* is a lead disc nearly sufficient to balance the portion of the pointer below *b*.

The result of this arrangement is that if *a* is moved relatively to *b*, this movement is magnified at the end of the pointer D. The sensitiveness of the instrument may be judged of from the fact that the pressure of my finger on the side of a stone column 2 feet square and 5 feet high is shown by a deflection of 4 or 5 millimetres at the end of the pointer. On the relief of pressure the pointer returns to its central position. To

FIG. 2.



obtain records, at intervals of every five minutes the current from an induction coil is sent down the pointer D, from which it passes as a spark through two strips of paper moving at right angles over the surface of a brass plate. One strip of paper moves north and south, and the other east and west. In this way a magnified representation of the position of the pendulum, drawn as a series of holes, is obtained. The magnification is about seventy times. Every hour a long contact makes a large hole.

As a check to the observations two slightly different instruments are worked simultaneously by the same current, these instruments being on different columns in rooms about 60 or 80 feet apart.

Thus far the results have not been analysed, but the following facts are clear :—

1. Sometimes for days both instruments give a continuous series of holes in a straight line.

2. Sometimes the holes are so multiplied by the trembling of the pointer that a broad line of holes is obtained. These tremors last from 2 to 10 hours.

3. Sometimes the pointer has slowly moved from side to side, giving a clearly defined set of holes marking two or three waves. The amplitudes of their waves, as shown on the diagram, are from 1 to 4 or 5 mm.

Their period varies from 15 to 60 minutes. In these records, which may possibly mean tips of the soil, the two instruments only occasionally agree.

4. Earthquakes are clearly shown by the pointer swinging about and making a series of holes up to the edges of the bands of paper. The relation, if there be any, between these various movements I have not yet determined. As the instrument is simple and inexpensive and satisfactory in its working, I am anxious that it should be brought to the notice of all who are interested in these observations. In connection with these observations I may mention that in September of last year, in conjunction with Mr. W. Wilson, C.E., and Mr. Mano, of the Imperial College of Engineering, I carried one of these instruments to the summit of Fujiyama, which is about 12,365 feet in height. Whilst on the top we were unable to undress, wash, or eat anything but the plainest of food. These and other discomforts, amongst which were the difficulties of breathing, prevented our remaining on the mountain for more than five days.

During this time we obtained observations during the day and night extending over a period of three days. These observations were made by observing the position of the end of the pointer as it moved across a scale of millimetres. The instrument was installed on the top of a very large block of lava, deeply buried in ashes, in the corner of a stone hut in which we slept. It was covered with a wooden case. Outside of this there was a tent made of oiled paper. The instrument was, therefore, well protected against currents of air. Before commencing readings the weight was suspended for about fifteen hours by the same wire on which it had hung for many weeks when in Tokio. To test the effects of moisture in the instrument, at the end of the observations I poured a large quantity of water all round the block of lava forming the support. This produced no visible change in the reading of the instrument.

The scale from which the readings were made, and which was immediately below the end of the pointer, was a piece of metal on which there were a series of concentric circles at intervals of a millimetre. A series of straight lines crossing the centre of these circles gave the points of the compass. Had the scale been a series of lines at right angles to each other, the readings would have been more definite. The results of interest connected with these observations are:—

1. That the movements on the top of the mountain were much greater than those which I usually observe in Tokio.

2. The tremors, or slight swing-like movements of the instrument, did not necessarily accompany the wind.

3. That during the heavy south and south-east gales the direction of displacement of the pointer was towards the south-east, which is the same result as would be obtained if the bed plate of the instrument were raised on the south-east side, or if the mountain had tipped over to the north-west.

My colleague, Mr. T. Alexander, treating Fuji as a conical solid made of brick, with a wind load of 50 lbs. on the square foot, found the slope and deflection of a point 100 feet below the apex of the cone. This calculated slope was two or three times greater than the greatest deflection which I measured.

As it is difficult to imagine that a mountain could suffer deflection by a wind pressure, I will not insist upon the fact that deflection actually

occurred. It is certainly curious that the results of calculation and observation should point in the same direction.

If the observed movements of the pendulum were due to a tip of the mountain, they might equally well have been observed as its base.

The actual observations are given in the following tables :—

1884. Day	Hour	Temperature Fahr.	Barometer	Pendulum	Direction from starting	Remarks
August 12	10.0 A.M.	50°	19·02	0·50	N.W.	Almost still
	11.45	50	19·02	0·50	N.W.	Slow swing from 0 to 1 on N. S. line
	12.30	51	18·97	1·00	NN.W.	Still
	1.0 P.M.	51		0·00		Now and then a slight motion. Temp. in sun 92° F.
	3.0	53	18·97	1·00	S.E.	Slight swing in N.E. and N. quadrant from 0 to ·5
	4.0	50	18·95	3·00	S.E.	Slight movement. Strong wind W. to S.
	6.0	48	18·95	4·00	S.E.	,, ,, ,,
	7.30	46	18·95	4·20	S.E.	Slight movement. Outside temp. 6° C. = 42° F.
	9.0	46	18·90	3·00	S.E.	Slight movement. Strong S. wind
	10.0	46	18·95	3·00	S.E.	Very slight motion. Strong S. gale
August 13	0.45 A.M.	46	18·95	2·00	S.E.	Slight motion. Strong S. gale
	4.30	42	18·92	1·50	SS.E.	Slight motion. Swings from 1 to 2·5 S.E. to S. Strong gale
	8.0	45	18·92	2·50	S.E.	Swings 2 to 3 N. and S. South wind. Gale abating
	9.30	45°	18·92	1·50		Swing 1 to 2 in the E. and N.E. quadrant. Mist and rain. S. wind
	10.30	45	18·90	1·50		,, ,, ,,
	12.0	45	18·90	1·50		Slight swing in E. and N.E. quadrant. Still strong S. wind and rain
	1.30 P.M.	46	18·87	1·00		Slight swing in E. and N.E. quadrant. Strong S.E. wind and rain
	2.45	47	18·87	1·50		Slight swing now and then, ·5. Strong S.E. wind and rain
	4.45	48	18·87	2·00		Swings 1·5 to 2·5. Barometer pulsating ·01 in. Wind abating, rain continues
	7.0	50	18·91	1·50		Slight swing 1 to 2 E. and W. No wind. Mist
	9.0	46	18·95	2·25		Swing 2 to 2·5 on E. line. Slight W. wind. No rain
August 14	0.15 A.M.	46	18·95	2·50		Swing 2 to 3 on E. and S.E. quadrant. Fine night. Moon up
	3.0	44	18·96	2·00		Swing on division 2 N.E. and S.W. In S.E. quadrant

1884. Day	Hour	Temperature Fahr.	Barometer	Pendulum	Direction from starting	Remarks
August 14 (*cont.*)	6.0	43	18·96	2·50		Swing on S.E. line, ·5
	7.30	45	19·00	3·50		Swing on E. and S.E. quadrant between 3 and 4, S.E. and N.W.
	11.30	46	18·99	4·50		Swing on E. and S.E. quadrant, now and then swings to 5. Position of pointer E.S.E.
	1.0 P.M.	48	18·97	5·50		Swing motion in E.S.E. quadrant
	2.10	46	19·00	6·00		Slight E.W. motion in E.S.E. quadrant
	3.0	48	18·99	6·00		,, ,, ,,
	4.0	47	19·01	6·25		Slight E.W. motion in E.S.E. quadrant. Slight W. wind
	5.0	47	18·98	6·25		,, ,, ,,
	6.0	46	18·98	6·25		Slight N.E. S.W. motion in E.S.E. quadrant
	7.0	46	18·95	6·00		Slight N.E. S.W. motion in E.S.E. quadrant. Wind dropping
	8.0	46	19·00	5·00		Slight motion E.S.E. quadrant. W. wind rising
	9.30	45	19·00	5·00		Slight motion E.S.E. quadrant. Wind dropping
	11.30	44	18·95	5·00		Swing 4·5 to 5·5 in E.S.E. quadrant. W. wind strong
August 15	1.0 A.M.	42	18·90	5·25		Swing 5 to 5·5. Strong W. wind and fog
	3.45	42	18·93	4·50		Swing 4 to 5. Strong W. wind and fog
	7.0	44	18·90	4·00		Nearly still. Strong S.W. wind and fog
	8.0	44	18·94	4·00		Slight movement. Wind dropped. Heavy fog
	9.0	44	18·94	4·00		In E.S.E. quadrant still. S. wind gentle

After this last observation a quantity of water was poured round the foundation, and during the next hour several observations were made, but no change in reading could be detected.

All the thermometer readings are about 1·5° too high, and the barometer readings ·068 too high. Although none of the temperature readings indicate freezing, water in the doorway of the hut was several times thinly covered with ice. Under the boards on which we slept there was a thick bed of ice, and in the adjoining crater, about 600 feet deep, there were large beds of snow.

Earth Temperatures.

In January a bore-hole was sunk in the grounds of the Imperial College of Engineering, about 100 feet in depth. The section was approximately as follows:—

Earthy materials and sand	78·0 shaku
Very hard gravel	2·5 „
Fine gravel	2·0 „
Sand	6·5 „
Gravel	10·5 „
Taff (a soft clay-like rock)	4·5 „
Total	104·0 „

The feet given are Japanese shaku (shaku = feet). On February 17, a series of thermo-electric junctions were lowered down the hole, one near the bottom, one at approximately 75 feet, another at approximately 50 feet, and a fourth at 21 feet. The bore-hole was then filled up by slowly pouring in from day to day a mixture of clay, sand, and water. The junctions consisted of thick iron and copper wires dipping into a glass tube filled with mercury. All the copper elements had distinct cables leading to the surface. The iron elements at the different stations were joined to a single iron wire leading from the bottom to the top of the hole. The glass tubes were protected by brass tubes. All these junctions, together with a fifth junction buried just below the surface of the ground, can be compared with a similar junction in a water-bath in the Physical Laboratory. The whole of these arrangements are under the charge of Professor Fujioka, who at some future time will probably give some detailed account of his observations. The first records were made on March 26 and ran along steadily until April 16, when, for causes which are unknown, there was suddenly an increase in current, to balance which the water-bath had to be raised to a temperature about double that which had been required a few hours previously.

The first portion of the observations are as follows:—

		T. 25	T. 50	T. 75	T. 100
March 26	2.40 P.M.	15°·0 C.	16°·4 C.	17°·8 C.	18°·00 C.
	4.0 „	15°·0	16°·2	18°·2	18°·10
„ 27	10.0 A.M.	15°·2	16°·2	18°·0	17°·80
	2.0 P.M.	15°·2	16°·1	17°·8	17°·10
„ 28	8.30 A.M.	15°·2	16°·1	17°·8	17°·20
„ 30	8.0 „	15°·1	16°·1	17°·6	17°·00
„ 31	10.30 „	14°·4	—	17°·0	16°·95
April 1	10.30 „	14°·6	15°·8	17°·4	17°·40
	3.0 P.M.	15°·0	16°·0	17°·4	17°·80
„ 2	10.0 A.M.	14°·0	15°·2	17°·0	17°·80
„ 9	10.0 „	14°·8	15°·8	17°·4	16°·80
„ 15	10.0 „	14°·9	—	17°·1	15°·80

Eleventh Report of the Committee, consisting of Professor E. HULL, Dr. H. W. CROSSKEY, Captain DOUGLAS GALTON, Professors J. PRESTWICH *and* G. A. LEBOUR, *and* Messrs. JAMES GLAISHER, E. B. MARTEN, G. H. MORTON, JAMES PARKER, W. PENGELLY, JAMES PLANT, I. ROBERTS, FOX-STRANGWAYS, T. S. STOOKE, G. J. SYMONS, W. TOPLEY, TYLDEN-WRIGHT, E. WETHERED, W. WHITAKER, *and* C. E. DE RANCE (*Secretary*), *appointed for the purpose of investigating the Circulation of Underground Waters in the Permeable Formations of England and Wales, and the Quantity and Character of the Water supplied to various Towns and Districts from these Formations. Drawn up by* C. E. DE RANCE.

YOUR Committee have not been able to include in the present report information which would be of considerable value in drawing up a final report on the result of their twelve years' labour. They therefore consider they will best carry out the instructions which you gave them in 1874 by continuing their investigations for another year. That this should be done is the more important from the fact that the present dry season, following the dry summer and autumn of last year, has, by drying up surface springs, and by the diminution of streams, exhibited the importance of the deeper-seated underground stores, but at the same time, has shown that, in estimating the quantities of water to be derived from such sources, it is of the highest importance to obtain data as to the yield of deep wells and borings in years of drought, and to obtain accurate knowledge of the extent of the depression of the level of underground waters. Your Committee had hoped that observations made in the United States or in Canada on the filtering powers of sandstones, the influence of barometric pressure and other changes on the height of underground waters, and on the influence of earthquakes, might have been obtained, but they regret that no such communications have been received.

Mr. C. E. Peek, F.R.Met.Soc., of Rousdon Observatory, three miles west of Lyme Regis, has offered to carry out observations on his well, which is 200 feet in depth and 500 feet above the sea, as regards temperature and changes of level due to alteration of atmospheric pressure or astronomical causes. Mr. I. Roberts, F.G.S., of Maghull, has continued his observations in this direction, but prefers to communicate them as an independent paper to the Royal Society of London. Mr. Roberts's experiments on the action of sandstone in extracting the salts of saline solutions, published as an appendix to the Underground Water Report presented at Dublin in 1878, have been attacked by Mr. William Ripley Nichols, Memb. Boston (U.S.) Soc. of C.E.,[1] who considers 'that the salt solution placed on top of the block forced before it the water already contained in the pores of the stone, and mixed with it but little. . . . If the stone had been perfectly dry there would have been no effect observed, unless, as is the case with most sandstones, the rock actually contained some salt to start with, in which case the first portion of the liquid that came through would contain a trifle more salt than the subsequent

[1] *Journal of the Association of Engineering Societies*, 1884, vol. iii. p. 144.

portions.' In reply, Mr. Roberts writes, 'I would immediately have set to work to verify the results which I had obtained seven years ago; but after studying Mr. Ripley's methods of research, and his inferences, I do not find that he has proceeded on lines that are even approximately reliable as tests of my results.' He asks, 'Is it proof, or reasonable inference, that, because Ohio stone, which contains salt in its pores, does not filter salt from water, neither, therefore, does Triassic sandstone, which does not contain salt, from Everton [Lancashire], filter any?'

It is therefore necessary for Mr. Ripley, to establish his position, to repeat his experiments with sandstones which either contain no salt or from which it has been totally removed. He gives no record of such an experiment in his paper, and Mr. Roberts's experiments remain unassailed.

Mr. Roberts draws attention to the *hygroscopic* properties of the New Red Sandstone, or its power of rapidly absorbing moisture from the atmosphere and giving it off again on any increase of temperature. Four years ago he selected a cube of Bunter sandstone, and depriving it of moisture, weighed it, and found the weight 14,553 grains. This weight he adopted as zero. On exposing the stone freely to the air it rapidly and steadily absorbs moisture, varying from hour to hour with the changes in the humidity. In June, 1883, its weight of moisture varied between 38 and 74 grains, in December of that year it varied between 73 and 107 grains.

Details of Wells and Borings, Berkshire.

Swindon Local Board Well. Mr. R. W. Mylne, C.E., F.R.S., Engineer; Mr. R. Spellor, Blackfriars, London, Contractor. Works consist of a 6-feet shaft of 110 feet depth, with boring to 500 feet below the top of the shaft; at the bottom of the shaft is a chamber of 14 feet, from which is driven an adit level to the side of the hill, tapping the water met with at the bottom of the shaft.

Details and Specimens collected by C. E. De Rance.

From surface feet			Thickness feet
107.	Chalk		107
110.	Sand (upper greensand)		3
248.	Grey clay (gault)		138
250.	Grit (lower greensand?)		2?
322.	Grey clays, harder 310 feet from surface	72 feet	250
500.	Shelly clays (boring discontinued)	178 "	
			500

Comparing these thicknesses with those given in the Horizontal Section of the Geological Survey traversing this area, it is probable that the 250 feet of clay below the grit all belong to the Kimmeridge clay.

	Geological Survey feet	Swindon Section feet
Upper greensand	60	3
Gault	140	138
Lower greensand	40	2?
Kimmeridge clay	280	250
Coral rag	40	
Oxford clay	500	

Denbighshire, N. Wales.

Boring on the London and North-Western Railway, Foryd, near Rhyl, Collected by C. E. De Rance, per Mr. A. Strahan, F.G.S., from Mr. Leigh Howell, of Bagillt.

			ft.	in.
1.	Clay		2	0
2.	Sand		19	0
3.	Gravel		4	0
4.	Mud and clay		16	6
5.	Turf	Post-glacial deposits 58 ft. 4 in.		6
6.	Blue clay		10	4
7.	Turf		1	6
8.	Blue clay		1	0
9.	Gravel		3	6
10.	Red clay		9	8
11.	Red sand		1	0
12.	Dark sand		6	0
13.	Red sand	Glacial deposits 39 ft. 8 in.	1	0
14.	Sand and gravel		7	6
15.	Red clay		8	6
16.	Sand		4	0
17.	Clay and gravel		2	0
18.	Red sandstone		93	0
19.	Shale			6
20.	Red sandstone		1	0
21.	Red shale		2	0
22.	Red sandstone		33	10
23.	Red shale		3	0
24.	Red sandstone		10	10
25.	Red shale	New Red Sandstone 499 ft.		6
26.	Rock		2	0
27.	Red shale		1	6
28.	Red sandstone		5	6
29.	White sandstone, with black shade.		1	2
30.	Red sandstone		89	8
31.	Red shale			8
32.	Red sandstone		246	0
33.	White and red rock		7	10
34.	Red marl		8	0
35.	White rock		2	0
36.	Red shale	Coal Measures 149 ft. 5 in.	45	1
37.	Red shaly rock		83	8
38.	White hard rock		3	6
39.	Red shale rock		7	2
			746	5

Lincolnshire Wells and Borings.

Grimsby Waterworks Co. Wells.

Collected by C. E. De Rance from Messrs. Mather and Platt.

Boring west of Grimsby.

From surface ft.	in.		Thickness ft.	in.
21	0	1. Very soft clay, full of vegetable matter	21	0
24	6	2. Gravel and sand	3	6
29	6	3. Clay	5	0
31	6	4. Rough gravel and small flints	2	0
33	6	5. Fine soft clay and small flints	2	0
45	0	6. Rough gravel	11	6
60	0	7. Fine gravel	15	0
75	0	8. Chalk, very hard. Water then rose to 4 feet above the surface in large volume	15	0
			75	0

Boring east of Grimsby, near Cleethorpes.

From surface ft.	in.		Thickness ft.	in.
84	0	Stiff bluish clay, with flakes of chalk	84	0
99	0	Sand and gravel	15	0
224	0	Chalk, with flints in beds	125	0
			224	0

In the Cleethorpes boring the top of the chalk was very rotten, and had to be tubed out down to 120 feet from the surface, or 21 feet from the top of the chalk. The yield from this boring is only about 180,000 to 192,000 gallons per day; but it is evident that the water is not tubed out from the upper part of the chalk, or not entirely so, from the fact that, when this quantity is pumped, the water-level being 24 feet from the surface, the neighbouring wells and bore-holes, none of which do more than penetrate the top bed of the chalk, all lose their supply of water.

At Grimsby Docks there is a well in the chalk 300 feet deep; the water is clear and palatable. Analysed by the Rivers Pollution Commission, was found to have a hardness of 22·1, of which 7·6 was permanent; chlorine was 5·00, in parts per 100,000.

From Mr. John Bennett, Goole, per H. Franklin Parsons, M.D., F.G.S. Section of Trial Boring at Reedness, five miles east of Goole, made by the late Mr. Egremont in 1835.

From surface ft.	in.			Thickness ft.	in.
1	6	1. Dark soil	Alluvial deposits	1	6
1	9	2. Yellow sandy warp		0	3
9	3	3. Dark blue warp		7	6
15	3	4. Fine blue clay		6	0
21	3	5. Blue sandy warp		6	0
30	3	6. Light grey sand, with water		9	0
42	0	7. Black moor earth, with some rotten wood		11	9
45	3	8. Strong blue clay	Drift	3	3
46	0	9. Grey sand, with water		0	9
56	3	10. Black gravel and quicksand		10	3
57	8	11. Red sand		1	5
63	0	12. Grey sand and gravel		5	4
66	4	13. Red sand		3	4
69	8	14. Gravel and sharp sand		3	4
72	10	15. Red marl, metal with grey specks		3	2
80	11	16. Red sandstone, with gypsum, and thin lists		8	1
90	1	17. Strong blue stone, with thin white beds		9	2
108	4	18. Dark red bind, with thin beds of gypsum		18	3
110	0	19. Strong blue stone		1	8
120	3	20. Red bind, with beds of blue stone		10	3
125	1	21. Blue stone		4	10
133	7	22. Red bind with thin white beds, and hard lists of blue stone		8	6
135	7	23. Blue bind		2	0
143	2	24. Red bind, with thin hard lists of blue stone and gypsum		7	7
151	10	25. Red stone		8	8
168	8	26. Red bind, with hard lists of stone and gypsum		16	10
173	0	27. Blue stone		4	4
190	11	28. Red bind, with thin beds of gypsum		17	11
192	8	29. Blue bind		1	9
199	4	30. Red bind, with thin beds of gypsum		6	8
199	6	31. Blue stone, and white parting		0	2
219	2	32. Red stone, with blue lists		19	8
241	8	33. Blue bind, with thin beds of gypsum		22	6

From surface ft.	in.		Thickness ft.	in.
247	2	34. Red stone	5	6
251	2	35. Blue stone	4	0
257	8	36. Red bind, with hard list and white partings	6	6
263	2	37. Red sandstone, with thin white partings	5	6
269	8	38. Blue stone, thin beds, and blue bind partings	6	6
286	2	39. Blue bind, with thin beds of blue stone	16	6
297	2	40. Red bind, with thin beds of gypsum	11	0
305	5	41. Blue bind, with soft beds of gypsum	8	3
337	10	42. Dark soft red bind	32	5
341	10	43. Blue stone	4	0
511	4	44. Red sandstone	169	6
513	4	45. Red bind	2	0
529	10	46. Red sandstone	16	6
533	4	47. Red bind, with lists of blue stone	3	6
766	10	48. Red sandstone	233	6
770	0	49. Red bind with bright shining specks	3	2
772	10	50. Dark red bind	2	10
784	4	51. Red sandstone	11	6
785	4	52. Dark red bind	1	0
804	10	53. Red sandstone	19	6
807	1	54. Red bind	2	3
881	4	55. Red stone	74	3
882	4	56. Red bind	1	0
906	10	57. Red stone	24	6
910	8	58. Soft red bind	3	10
930	10	59. Red sandstone	20	2
931	10	60. Dark red bind	1	0
955	10	61. Red sandstone	24	0
957	1	62. Dark red bind	1	3
995	4	63. Red sandstone	38	3
998	4	64. Light red sandstone	3	0
1029	0	65. Red sandstone	30	8
			1029	0

In abstract, the section will stand as follows:—

		ft.	in.
Beds 1 to 14.	Drift	69	8
Beds 15 to 43.	Keuper marls with hard bands and gypsum	272	2
Bed 44.	Red sandstone	169	6
Beds 45 to 47.	Red sandstone with 5½ feet of red 'binds'	22	0
Bed 48.	Red sandstone	233	6
Beds 49 to 62.	Red sandstone, with 16 feet 4 inches of red 'binds'	190	3
Beds 63 to 65.	Red sandstone	71	11
		1029	0

Out of 687 feet 2 inches of beds beneath the Keuper marls, only 21 feet 10 inches consists of red binds, the rest being 665 feet 4 inches of red sandstone of similar physical character from top to bottom. They have been referred by Dr. Parsons to the Bunter.

In considering their age and character, it may be useful to compare this section with the borings for salt in the Middlesbrough district, especially that at Saltholm Farm, on the Durham side of the Tees ('Sixth Report Underground Water'). I there suggest that 'the limestones, thick salt beds, and gypsum are probably referable to the Permian; the intervening beds of red sandstone, 832 feet, are probably referable to the waterstones and lower mottled Bunter, the Upper Mottled and Pebble Beds having thinned out.' From more extended investigation, I think it more probable that the pebbly character of the middle portion of the Bunter has died away northwards, and that the Middlesbrough section represents Waterstones, pebbleless Middle Bunter and Lower Bunter.

In the Lincolnshire area some sections collected by Dr. Parsons throw light on this inquiry. He describes the beds below the Keuper marls, in the surface sections as 'a loose red sand, or friable semi-coherent red sandstone, often micaceous, with more coherent clayey bands, and with occasional partings, or pockets of red, green, or yellow ochrey marl.' [1]

Trial Boring for Water, Booth Ferry Road, Goole, made by Goole and Hook Parochial Sanitary Committee in 1876. From Mr. Tudor, Surveyor, Goole, per Dr. Parsons.

From surface ft.	in.		Thickness ft.	in.
17	0	Warp, peat, and clay	17	0
25	0	Rough gravel	8	0
28	0	Warp clay, with a large pebble	3	0
34	0	Red sand	6	0
58	0	Hard, coarse, light red sand	24	0
68	0	Red marl	10	0
79	0	Hard sand	11	0
82	0	Red marl	3	0
108	0	Hard sand	26	0
109	0	Red marl	1	0
170	0	Hard sand	61	0
173	0	Red marl	3	0
176	0	Hard coarse sandstone, with small pebbles	3	0
260	0	Red sandstone and marl mixed	84	0
282	0	Red sand	22	0
284	2	Stiff red marl	2	2
306	3	Marl and red sand	22	1
366	0	Red sandy marl	59	9
			366	0

In abstract, this section gives drift probably 28 feet, red sand 338 feet, of which 19 feet were marl, if the red sandy marl last penetrated be omitted, which added gives an entire thickness of marl of just 80 feet. The occurrence of the small pebbles at 176 feet and the thick marl are worthy of note in this section, and differ from those adjacent; they are probably referable to the Waterstones.

C. E. De Rance, from Dr. Helliwell, per Dr. Parsons. Well deepened in 1876. Helliwell's Brewery, Rawcliffe.

From surface ft.	in.			Thickness ft.	in.
18	0	1.	Old well	18	0
45	0	2.	Yellow sand	27	0
47	0	3.	Blue clay	2	0
47	6	4.	Peat	0	6
59	6	5.	Clay with gravel	12	0
200	0	6.	Red sand, with thin marl bed at 139 feet	140	6
				200	0

Artesian well at Rawcliffe Halls, 1877. *Details from Mr. Tudor, Surveyor, Goole, per Dr. Parsons.*

From surface ft.	in.		Thickness ft.	in.
16	0	1. Silty stiff red warp	16	0
130	0	2. Red sand and marl	114	0
250	0	3. Coarse, loose red sandstone and marl	120	0
			250	0

[1] *Proc. Geol. and Poly. Soc. of West Riding of Yorkshire,* 1877, p. 216.

Well near Rawcliffe Station. Per Dr. Parsons, 1876.

From surface ft.	in.		Thickness ft.	in.
3	0	1. Black sand	3	0
8	0	2. Brown coarse sand	5	0
16	0	3. Mottled brown clay	8	0
		4. Red sand		

These soft 'red sands' and 'loose sandstones' would appear to be referable to the Keuper waterstone, or are the representatives of the Cheshire Frodsham beds, which have been observed eastwards by Mr. Aveline, F.G.S., and myself as far as Ashbourne in Derbyshire.

Trial Boring for Water at New Bridge, near Snaith, in ancient course of the River Don, made in 1876 *by the Goole Local Board. From Mr. Tudor, Surveyor, Goole.*

From surface ft.	in.		Thickness ft.	in.
46	0	Brown warp, peat, and loam	46	0
51	0	Gravel, with magnesian limestone fragments	5	0
56	0	Coarse reddish brown *sand* (decomposed rock ?)	5	0
57	0	Light green marl	1	0
80	0	Red marly *sandstone*	23	0
87	0	Coarse red *sandstone*	7	0
130	0	Red marly *sand*	43	0
133	0	Red sand, with green marl	3	0
170	0	Red marly *sand*	37	0
173	0	Blue marl	3	0
175	0	Red marl	2	0
263	0	Red marly *sand*	88	0
265	0	Variegated marl	2	0
309	0	Red marly *sand*	44	0
329	0	Coarse red *sand*	20	0
377	0	Red marly *sand*	48	0
379	0	Variegated marl	2	0
403	0	Red marly *sand*	24	0
404	0	Variegated marl	1	0
500	0	Red marly *sand*	96	0
			500	0

This section gives, in abstract, drifts probably 51 feet, and 449 feet of red sandstone, red sand, and coarse red sand, with 11 feet of intercalated marls, the whole of which may be regarded as one series, and compare well with the Goole section, and may be referred to the Keuper waterstones, and might for their important thickness be called the *Goole beds.*

It may be well to reproduce the section of the Selby Waterworks, obtained from Mr. Wetherill by Professor Green, F.G.S.

Surface level $20\frac{1}{2}$ feet above Ordnance datum; the water out of a 6-inch bore-hole rises to 16 feet above Ordnance datum.

From surface ft.	in.		Thickness ft.	n.
5	0	1. Alluvial soil	5	0
29	0	2. Clay	24	0
30	0	3. Sand charged with water that one man could pump	1	0
54	0	4. Clay	24	0
75	0	5. Quicksand. Strong spring of water at base	21	0
		6. Red sandstone	18	0
93	0	7. Marl, resembling 'fullers' earth'	0	1

From surface ft.	in.		Thickness ft.	in.
		8. Red sandstone	10	3
103	3	9. Grey sandstone	0	1
		10. Red sandstone	64	9
		11. Red hard sandstone	118	6
		12. Very hard rock	10	6
		13. Red sandstone	6	9
		14. Very hard rock	4	9
330	8	15. Hard rock	22	0
			330	8

Here there was 75 feet of drift, all the remainder being more or less hard red sandstone, without the intercalated marl beds observable in the Goole section, which are presumably above those penetrated at Selby, which may be referred to the Pebble Beds.

Boring at Donington, on west side of River Bain. Communicated by Mr. Edward Bogg, to the Geol. Soc., London, 'Trans. Geol. Soc.' 1816

	ft.	in
1. Clay soil	3	0
2. Dark coloured clay	9	0
3. Soft grey shale, with fossils	1	0
4. Blue argillaceous stone	0	5
5. Dark coloured clay	3	1
6. Soft grey shale	1	0
7. Laminated clay, slightly indented	23	2
8. Soft grey shale, slightly inflammable	5	3
9. Ditto, darker coloured	5	3
10. Indurated clay, with white fossils	37	6
11. Ditto, but harder and blacker	7	3
12. Dark coloured bituminous inflammable shale	6	0
13. Dark blue ironstone	0	3
14. Laminated indurated clay, with fossils	33	0
15. Ditto, harder fossil impressions in pyrites	10	4
16. Dark blue clay (iron) stone	0	4
17. Hard indurated laminated clay, with pyrites	18	4
18. Laminated bituminous shale, with fossils	1	10
19. Dark blue ironstone	0	2
20. Laminated bituminous shale, like 18	11	0
21. Dark blue ironstone	0	1½
22. Laminated bituminous shale, like 18 and 20	18	10½
23. Dark indurated clay, with fossils	3	6
24. Laminated bituminous shale, like 18, 20, and 22	9	0
25. Dark clay, like 23	5	0
26. Laminated bituminous shale, like 24, &c.	4	6
27. Dark clay, indurated clay, like 25	30	3
28. Grit	0	2
29. Brown laminated shale	0	2
30. Clay (iron) stone	4	10
31. Hard laminated bituminous shale	3	2
32. Clay (iron) stone	2	0
33. Hard laminated bituminous inflammable shale	2	4
34. Inflammable compact shale	3	0
35. Hard laminated shale, very inflammable	3	7½
36. Dark blue compact shale, with bituminous bands	13	9½
37. Very inflammable shale	0	2
38. Hard, dark, blue, compact shale	3	8
39. Clay (iron) stone	1	0
40. Ditto, but not so hard	1	0
41. Hard, dark, compact shale, like 38	22	10
	309	0

The whole of the above boring appears to be in the Kimmeridge clay.

Mr. Dickenson, F.G.S., in H.M. Inspector of Mines Report for 1881, describes a boring, 1,140 feet deep, put down west of Horncastle, at a point situated on the Kimmeridge clay, near the base of the Cretaceous rocks, which was carried to a depth of 1,140 feet, and is stated to have reached the Triassic sandstones, in which a brine spring was discovered. In this case the Kimmeridge clay, Lower Oolites, Lias, Rhætic, and Keuper marls must have been penetrated.

At Stamford a futile boring for coal was put down by the late Marquis of Exeter to a depth of 500 feet, which, commencing at a similar geological horizon to the two last described borings, failed to reach the base of the Lias at that depth.

A boring at Boston Market Place has already been described in the Report for 1878; some further details communicated to the Royal Society may be found in the 'Phil. Trans.' vol. lxxvii. The well was sunk in 1747 to a depth of 186 feet, and deepened in 1783 to its present depth of 478 feet.

Details of Cores brought up by Diamond Boring Company at Scarle, nine miles S.W. of Lincoln, near boundary of parishes of Scarle and Swinderby, and about 100 *yards from the Lincoln and Nottingham Railway. By Professor Hull, F.R.S.*

Feet from surface, about				Feet thickness, about	
10	0	Alluvial or drift deposits	Drift	10	0
75	0	Blue lias limestone, clay and gypsum	Lower Lias	65	0
180	0	Green silicious grits	Rhætic	66	0
714	0	Red and grey marls, with greyish fine sandstone and fibrous gypsum	Keuper marls	573	0
790	0	Fine grained greyish sandstone, with water feeder of 11 galls. per minute, at 834 feet.		76	0
906	0	Ditto	Lower	116	0
912	0	Greyish shale	Keuper	6	0
918	0	Coarse grey grit	sand-	6	0
919	0	Greyish shale	stones or	1	0
950	0	Hard white freestone, with a 50 gallons of water per minute feeder, at 9·50 feet, rising to 52 feet above the surface, according to Mr. Dalton, F.G.S.	Water-stones, 244 feet	31	0
958	0	Hard grey shale		8	0
1005	0	Soft sandstone	Pebble	47	0
1096	0	Reddish sandstone	Beds of	159	0
1164	0	Band of blue shale	the	1	0
1238	0	Reddish brown coarse sandstone	Bunter,	174	0
1278	0	Conglomerate of quartzite pebbles	320 feet	40	0
1357	0	Reddish brown sandstone, with red marl	Lower Mottled sand-	79	0
1500	0	Reddish brown sandstone, very soft	stone, 222 feet	143	0
1618	0	Red marls (Upper Permian)	Upper Permian	118	0
1623	0	Blue shale and stony shale		5	0
1638	0	Light yellowish magnesian limestone	Permian	15	0
1645	0	Stony shale	mag-	7	0
1662	0	Light yellowish magnesian limestone	nesian	17	0
1688	0	Blue and red marls, with gypsum	lime-	26	0
1800	0	Red marl and magnesian limestone	stone	112	0
1816	0	Yellowish magnesian limestone, with *Schizodus*	series, 266 feet	16	0
1884	0	Ditto, with selmite		68	0

Feet from surface, about				Feet thickness, about	
1900	0	Red sandstone	Lower Permian sandstone	16	0
2030	0	Earthy limestones, shales, with *Anthracosia*, coarse grit, breccia, and marls .	Carboniferous	130	0
				2030	0

Tabulating these figures gives the following totals :—

		ft.	in.	ft.	in.	
	Drift	10	0			
	Lias	65	0			
	Rhætic	66	0			
817	Keuper marls . .	573	0	736	0	878
	Waterstones . . .	244	0	142	0	
	Bunter	542	0			
	Permian	400	0			
	Carboniferous . .	130	0			
		2030	0			

Mr. Dalton, F.G.S., late of the Geological Survey of England and Wales, has given some different thicknesses as the result of his examination of the cores which he has had the opportunity of inspecting, his alternative figures are given in the second column above. He refers to this boring as the Collingham boring, and regards the locality as a centre of subsidence in Triassic times, and considers the beds there to be of abnormal thickness.

Yorkshire Coal Measures.—The following information as to the thickness of the intercalated sandstones, in the Yorkshire Coal-measures, and their water-bearing capacity, which is of considerable value both as to quantity and quality, have been obtained from Professor Green, M.A., F.G.S., of the Leeds University.

The 'Oakenshaw' or 'Clifton' rock is generally a massive false-bedded sandstone, much divided by joints; it is close in grain and gritty in texture; it furnishes an excellent and durable building stone. In some districts it is separated into two beds; in this case the upper bed is called the 'Shertcliffe Bed Seatstones.' In the Clifton district the two beds, with intervening shales, together form the 'Clifton rock.'

The 'Thornhill rock,' the most important middle coal-measure sandstone in the northern part of the field, is the chief source of building-stone in the district; it is generally close grained and thin bedded, but is sometimes coarse; in places it is much traversed by vertical joints. It occurs below the *Haigh Moor coal*, and also bears the names of the Dewsbury Bank, Morley, Middleton, Robin Hood, and Oulton rock; below it is the *Joan coal.*

'Parkgate rock,' 'Croppergate,' or 'Birstall rock' occurs above the Parkgate coal. At Scholes Colliery it is 80 feet thick; at the Nunnery sinking 90 feet; at the old Pits Moor Collieries it is nearly 170 feet, where it is thickest; it is thickly bedded, rather coarse, and much jointed, and yields abundance of water, necessitating heavy pumping to work the coal when there is no intervening bind above the seam, as is sometimes the case. It is largely quarried at the village of Bradgate, and hence William Smith called it the 'Bradgate rock.'

The 'Woolley Edge rock' is believed to have been deposited in an area bounded by a line running west between Pontefract and Castleford,

by Normanton, a little beyond Wakefield; then south by Woolley Edge, and passing west of Barnsley, ranging S.E., to Hemingfield. To the S.W. it is coarse; at Wakefield finer.

The 'Woolley Edge rock' at Hemingfield, at Lundhill Colliery, consisted of 82 feet 6 inches of sandstone, 23 feet 5 inches of shale, and 24 feet 4 inches of sandstone, overlying the *Wathwood coal*. At Wombwell Main it was 120 feet 2 inches, and 12 feet 5 inches of shale intervened between it and the *Wathwood coal*. North of Dillington it contains pebbles as large as a hazel nut. East of Wakefield, at Whitwell Main Colliery, it lies above the *Wakefield coal*; 38 feet of it is described as 'bleeding rock,' exuding much acrid water, that blisters the hands of the sinkers.

The 'Oaks rock' is so called at Barnsley; at Trenton and the district S.E. of Sheffield it is called the 'Trenton rock.' It can be traced on its outcrop as far as Heath; east of Wakefield it appears to thin away along a line running roughly north-west and south-east through Normanton. It usually carries a large quantity of water—when it is split up with shales the quantity is less; it is largely quarried for building-stone and making grindstones, the most important quarry being near Barnsley. When this rock attains its full thickness it is estimated to be 100 feet, and its base to be 850 feet above the *Barnsley coal*. At Wath Main Colliery the total thickness of rock was 55 yards; it yielded an enormous quantity of water, one feeder alone yielding 3,000 gallons per minute after the tubing was in the shaft, but before it was fully 'wedged' the yield for months was 18,000 gallons per minute.

The 'Pontefract rock' is water-bearing.

Drought of 1884.

Mr. G. J. Symons, F.R.S., finding that the small rainfall of the year had had considerable effect upon the level of water in wells, &c., invited his staff of 2,600 unpaid observers to report any facts within their own knowledge bearing on this question. The following notes are the result of his inquiries:—

South-Eastern Counties.

Reigate.—Shallow wells wholly failed; springs and watercourses had not begun to run at the close of the year.

Tenterden, Summerhill.—River Rother was nearly dry; wells and ponds were nearly all dried up.

Tunbridge Wells.—Springs and wells very low, many dried up.

Maidstone, Lower Tovil.—The Loose stream dry. River Medway very low, and water very clear.

Sheldwick Vicarage.—Springs very low to end of year; water in well 170 feet deep—4 feet below average.

Sevenoaks.—Springs low in autumn; average flow not restored at end of the year.

Wrotham.—Two wells in chalk, 100 feet deep, were dry in autumn, and continued so at the end of the year.

Ospringe, Lorenden.—Strong spring from chalk hills, flowing 4 inches deep in a 4-feet channel, entirely stopped.

Chichester, Westgate.—Surface wells dry; deep chalk wells low.

Midhurst, Cocking.—September to November, water lower than

before in memory of oldest inhabitant. Miller on stream from South Downs could only work one hour in twenty-four in November.

Horsham.—Shallow wells dry north of the town, on the anticlinal axis of the weald, at 245 feet above Ordnance datum. The supply at the waterworks was not affected: surface of well 177 feet above Ordnance datum; depth of well 75 feet, bore hole, 45 feet; total 120 feet, or 57 feet above Ordnance datum. The railway station well, within 90 feet of Ordnance datum, was not affected.

Falmer.—Wells dry in November; rose slightly in December. Springs very low at end of the year.

Lewes, Iford.—Wells, springs, and streams very low.

Warbleton Rectory.—Wells mostly dry in autumn.

Newick.—Many wells failed for first time.

Uckfield.—Driest year since 1858; heavy rain of September relieved drought, but the underground springs did not commence flowing until the continuous rains of December.

East Grinstead.—Many wells dry for first time.

Sandown, Isle of Wight.—Carisbroke Castle well, 240 feet, with an average of 70 feet of water in it, was dried up, it is reported, for the first time since 140 years.

Emsworth, Redlands.—Wells, springs, and streams ran dry; never dry before in 'memory of man.'

Alresford, Ovington.—High Downs wells failed.

East Worldham.—Wells 83 feet deep failed for first time; one 84 feet deep yielded a little water that could be pumped in a few minutes. Spring below the hill held out.

Micheldever, Northbrook.—The level of water in the chalk fell in autumn to a lower point than has been noted since 1870, and, though rising slightly in consequence of the December rainfall, was much below the midwinter average at the close of the year.

Andover, Red Rice.—Many wells dry. Mill and millstream lower than they have been for thirty years.

Rotherwick, Tylney Hall.—Wells dry; springs very low.

Blackwater, Hurstleigh.—Wells and streams very low.

Heckfield, Park Corner.—Driest of thirteen years. Wells failed on November 28, but began to fill November 30.

Newbury, Greenham.—Well for three months 10 feet below its average level, but was restored to normal level by end of year.

Hungerford, Dunford Park.—Springs never seen so low.

Lambourne.—The stream of the Lambourne river ceased running on October 13, and on the 19th the bed of the river (chalk) was dry. In December several wells dried up, and so continued to end of year.

Long Wittenham.—Driest year since 1874. Well 40 feet deep in greensand, 4 feet 6 inches lower than in 1883, and lower than it had been since 1871. Observations have been taken regularly since 1868. Wells in the gravel ran dry.

South-Midland Counties.

Watford, Wansford House.—Driest year since 1874. Deep chalk wells but little affected.

Royston.—Driest year since 1864; springs very low.

Thame, Aston Rowant.—Wells dry in September. Springs lower at end of year than for ten years previously.

Oxford.—Wells dry for first time in living memory.

Stanton St. John.—Springs very low at end of year.

Banbury.—Shallow wells and surface springs dry.

Oundle.—Shallow wells dry. New well carried to 70 feet without meeting with water.

Bedford.—Percolation (by Dalton gauge) through 2 feet 6 inches of soil of medium water-holding power, 5·93 inches.

Tempsford Hall.—Rivers and well all very low.

Cambridge, Fulbourn Asylum.—Water in well sank 4 inches, but supply plentiful.

Eastern Counties.

Leyton Observatory.—Ponds in Epping Forest dry for first time in twenty years.

Chelmsford.—Smallest rainfall since 1868. Many wells failed.

Dunmow.—Wells failed for first time.

Ipswich.—Underground water low, but no wells failed as in 1868. Rainfall one fourth less than the average.

Bury St. Edmunds.—Deep chalk well, the water was 6 feet below the average level.

South-Western Counties.

Maiden Bradley—In October and November, well water very short; some ran dry.

Trowbridge, Steeple Ashton.—Wells reduced in level at end of year; some exhausted.

Pewsey.—Some wells exhausted; all reduced.

Bishop's Cannings.—Well at Shepherd's Shore, which supplies Devizes, is 123 feet deep, with a 12-inch bore-hole, 25 feet lower; the water level at the beginning of the year was 63 feet from the surface, and fell to 96 feet at the end of the year. In 1880 the well was lowered 13 feet, and the bore-hole made, but the water had then never been so low as in 1884.

Mildenhall.—Driest autumn since 1856. Springs at Christmas lower than ever known, and still getting weaker, though the ponds were well supplied by rain of December.

Broad Hinton.—Wells on the Downs dry at the end of November.

Weymouth, Langton Herring.—Many wells exhausted for the first time.

Wimborne Minster, Chalbury.—Rainfall 4·14 inches below the average of twenty years.

Kingsbridge.—Springs failed for first time in memory of man; in many instances had not risen at end of year.

Kingsteignton.—Least rainfall of ten years. Wells deficient for five months.

Collumpton.—Well of 30 feet depth dry for first time.

St. Austell, Trevarna.—Wells dry for first time. Stream in adit driven into a high hill, that taps a spring 210 feet below the surface to supply Tregorrick, became almost dry.

Maker Vicarage (Devonport).—Wells and springs as low as in 1871; remained so until November 20, when a rise set in, and normal height was reached on November 28, before the heavy rain fell, which was not until December 2.

Bodmin.—Springs lower than for eighty years in November; they recovered about December 8.

Liskeard.—Rainfall 15·25 inches below average of twenty years. Springs failed throughout the district, but recovered in December.

Stratton, Week St. Mary.—Many wells dried up for first time, dry from middle of March to end of November.

Bude.—Springs never so low up to end of November.

Ilminster, White Lackington.—Two perennial springs failed.

Bridgwater, Ashford.—Streams supplying the water-supply were very low, but yielded more than the daily consumption of 200,000 gallons per day, the ordinary summer flow being four million gallons per twenty-four hours.

Kewstoke.—Many wells were dry until December rains.

West-Midland Counties.

Chipping Sudbury, Frampton Cotterell.—Wells were dry up to end of November.

Stroud, Brimscombe Vicarage.—Wells and springs dry for first time for years.

Gloucester, Barnwood.—Wells in gravel very low.

Hampen.—The springs that had already failed did so in October, and did not recover until the end of November.

Cheltenham, Battledown.—Hill streams dry for a long period, and wells supplied from sandbed in village were also dry. Cheltenham reservoirs dry.

St. Devereux, Whitfield.—Springs very low.

Ledbury, Putley Court.—60-feet wells very reduced in October and November; the 40-feet wells almost dry.

Hereford, Burghill.—Springs very low.

Pembridge, Marston.—Wells dry November and December.

Ludlow, Ashford.—Many wells dry in November; River Teme low from March to end of year.

Great Malvern, Madresfield.—Wells 16 to 25 feet deep, through marl subsoil, began to fail in October, and supply was limited to December. River Teme lower than for forty years.

Radway.—Driest year since 1870. Springs very low. Many wells no water until after Christmas.

North-Midland Counties.

Belvoir Castle.—Remarkable disappearance of subsoil water.

Oakham, Greetham.—Springs failed for a month.

Spalding, Pode Hole.—Fen drainage engines were standing still at end of year, and the water in Deeping Fen was allowed to rise to almost summer level to afford a supply for cattle, or in case of fire.

Sleaford, Bloxholm.—Wells 100 feet deep dry for weeks, as were springs and streams.

Horncastle.—Springs were dry that have not been so since 1826, from middle of August to middle of December.

Lincoln, Doddington.—Springs very low.

Alford, Sutton-by-the-Sea.—Streams fed by chalk very low, but wells did not fail.

Louth.—Springs very low; the Blow wells and other overflowing springs at Tetney were very low.

Ulceby, Limber Grange.—A well of 150 feet maintained its supply, but shallow wells dried in August.

Appleby.—Springs and wells low last three months of year.

Nottingham, Strelley Hall.—Driest year since 1874. A well in coal-measures, 45 feet deep, stood as follows:—At beginning of May, 36 feet of water in it; in middle of November, 15 feet of water in it, it being then somewhat higher than a short time before.

Newark, East Stoke.—Deep wells maintained their supplies, shallow wells failed. River Trent very low, May to September.

North-Western Counties.

Lymm.—Several wells dry; a perennial spring ceased running.

Maghull.—At Melling Quarry in pebble beds of Bunter, the surface of the underground waters was, on November 23, 1884, 42·5 inches lower than in 1883, 44 inches lower than in 1882, and 31·5 inches below the level of 1881; other conditions being the same.

Arkholm, Storr's Hall.—Dry August and September caused deficiency in wells, and small streams not to run.

Yorkshire.

Stainborough, Wentworth Castle.—Rainfall 10·17 below average of eight years. Springs very low.

Doncaster, Burghwallis Rectory.—Underground water lower than for seventy years. Well still falling at end of year.

Leeds, Oliver Hill, Horsforth.—Water supply from company failed, only supplied two hours a day to December 21. Water was pumped from water running out of Bramhope Tunnel, N.E. Railway.

Otterburn in Craven.—Traffic stopped on Leeds and Liverpool Canal for want of water; five inches of rain in July was all absorbed by ground, and added nothing to tributaries of Aire.

Hull, Derringham.—Seven months' drought; water supply deficient to end of year.

Wold, Newton.—In 1884, for third time since 1875, the Gypsey spring did not rise.

Masham, Burton House.—Springs failed to end of year.

Scarborough.—Chalk springs supplying the town were but little affected, but surface streams very low.

Northern Counties.

Shotley Bridge, Shotley Park.—Rain of July did not penetrate; springs failed until end of year.

North Shields, Clementhorpe.—Springs low to end of year.

Rothbury.—Springs at Whitton Town dry for three days at beginning of November; never known to fail before.

Cockermouth.—Wells failed in April, June, and November.

Wales and Monmouth.

Llanfrechfa Grange.—Springs very low.

Tredunnock.—Wells dry September to November.

Tredegar.—Water short for town supply, and iron and steel works, June till October.

Aberayron.—Many springs failed.

Llanidloes, Broomcliff.—Many springs dry.

Llandwrog, Glynllivon Park.—Springs dried up till late in autumn.

Llanfairfechan.—Springs disappeared until December, but a 40-feet well held out.

Report of the Committee, consisting of Mr. H. BAUERMAN, Mr. F. W. RUDLER, *and* Dr. H. J. JOHNSTON-LAVIS, *for the Investigation of the Volcanic Phenomena of Vesuvius. Drawn up by* H. J. JOHNSTON-LAVIS, *M.D., F.G.S.* (*Secretary*).

THE Reporter has to state that his work has been greatly hindered by the unfortunate outbreak of cholera in Naples, and the stringent local quarantine measures as a result thereof; these causes, combined with the superstitious fears of the people at seeing any stranger, prevented work on Vesuvius being carried out during the autumn of 1884. Nevertheless, daily observations were made of the variations in the activity of the volcano, of which a careful record has been kept.

All important changes of the crater-plain, and in the cone of eruption, have been photographed; copies of these photographs are exhibited at the meeting. Descriptions of the small eruption of May 2 of 1883 have already been given in 'Nature,' and the results of a microscopical examination of the sides of the remarkable hollow dyke then formed will soon be published. The Naples section of the Italian Alpine Club have generously undertaken to publish a journal of Vesuvius, which will contain reproductions of the photographs exhibited.

The third sheet of the geological map of Vesuvius and Monte Somma (scale 1 : 10,000) has been completed by the Reporter, and is exhibited at the meeting. It required thirty-three field days, not including preliminary knowledge obtained by many excursions during the previous years. The difficulties in the execution of this map have not been so much due to the complexity of geological structure as to the amount of detail necessary. This will be evident when the map is examined, for it will be seen that the gradual progress in the formation of a covering of soil to the lava-streams and the development of vegetation is indicated in no less than six different stages, thus rendering the map of agronomic value. Much care and patience was necessary in tracing out the course of ancient lava-streams now covered by a thick layer of loam. As a large part of the area is covered by habitations and by small gardens enclosed by high walls, each of which was separately visited, much time was spent in the work.

The relationship of the varying activity of a volcano in a Strombolian state to barometric pressure, the lunar tides, and rainfall, cannot but be regarded as important in solving some questions of vulcanology. Instrumental means of measuring such present so many practical difficulties that a scale of activity has been drawn up, which requires only a few minutes to learn, can be practised by any one with good eyesight and moderate intelligence who is within visual range of the volcano, and, above all, requires no further outlay than pen, ink, and paper. The objections will be mentioned after describing the process.

1*st degree.*—A faint red glimmer, above the main vent, interrupted by complete darkness.

2*nd degree.*—The glimmer is continuous, but the ejection reaches hardly above the central crater rim at the most.

3*rd degree.*—Glimmer continuous and well marked; the ejections are distinctly discernible as they rise and then fall on the slopes of the cone of eruption and roll down its slopes.

4*th degree.*—The ejections reach a considerable height, are brilliant, and light up the top of the great cone.

5*th degree.*—Verging on an actual paroxysmal eruption, the ejections are shot up very high, being only very slightly or not at all influenced in their course by a strong wind. Each explosion follows with much rapidity, and corresponds with the 'boati' heard all around the west, south, and south-east slopes of the mountain.

The objections to this method of registering the variations in the activity of a volcano are—

(*a*) Cloud-cap, which may for days cut off the view.

(*b*) After a great eruption, resulting in a deep crater, the changes of activity would be invisible from the neighbourhood of the mountain.

(*c*) It is only applicable after dark, so that usually only one observation a day can be made.

(*d*) Should lava be flowing from a lateral outlet, as is often the case, the level of the fluid in the chimney would vary as the outflow took place with greater or less rapidity, dependent on its blocking the passage more or less.

The Reporter thinks it desirable to introduce a description of this method into the report, so that it may be made use of in the case of other suitable volcanoes.

Report of the Committee, consisting of Mr. W. T. Blanford *and* Mr. J. S. Gardner (*Secretary*), *on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom. Drawn up by* Mr. J. S. Gardner, *F.G.S., F.L.S.*

[Plates I., II., & III.]

It may not be out of place to preface our First Report on the British Tertiary Flora with a brief summary of what is known regarding it at the present moment. Such a statement may be the more acceptable, as the subject is one, to promote the study of which the Association has made several grants in past years.

The following list will be found to comprise all the principal works on the British Tertiary Flora down to the year 1880:—

1833–5. Lindley & Hutton's 'Fossil Flora' contains descriptions of two Eocene Cycadaceous cones from the Thanet beds, and other Eocene plants are mentioned (pl. 125, p. 117, pl. 226, p. 189). In 1866 Mr. Carruthers redescribed these, referring them to *Pinus* ('Geological Magazine,' vol. iii. pls. 20, 21, p. 534).

1840. Bowerbank's (incomplete) 'History of the Fossil Fruits and Seeds of the London Clay' appeared, and remains to this day the most important work on our Eocene plants.

1851. The Duke of Argyll and Professor E. Forbes described the fossil leaves from Ardtun Head: nine were thought determinable ('Quart. Journ. Geol. Soc.' vol. vii. p. 103, pls. 2, 3, 4).

1854. Prestwich & Hooker figured several plants from Reading and Counter Hill ('Quart. Journ. Geol. Soc.' vol. x. pp. 88, 163, pl. 4).

1856. De la Harpe described the entire British Eocene Flora, as then known ('Bull. de la Société Vaudoise des Sciences Naturelles,' 1856). This was translated and illustrated in 1862 in the 'Survey Memoir on the Isle of Wight' (pp. 109, &c., pls. 5, 6, 7). About 300 specimens from various collections were brought together, and of species there were 43 determined from Alum Bay, 9 from Reading, 9 from Corfe Castle, 22 from Bournemouth, and 9 from the Upper Eocenes. In all 83 species, exclusive of those from Sheppey: but 23 occur in more than one locality, and the total number is thereby reduced to about 60.

1862. Heer & Pengelly's 'Lignite of Bovey Tracy' ('Phil. Trans.' 1862, part II.) was published 1863, when 50 species were described. In the same year Heer described the Hempstead Flora, 10 species in all ('Quart. Journ. Geol. Soc.' vol. xviii. p. 369).

These comprise all the works of any importance, but a complete list of references is given in the 'Introduction to the Palæontographical Society's Memoir on the British Eocene Flora for the year 1879.' Mr. Baily has, in addition, made several reports to this Association on the Antrim plants, and I have myself written from time to time on the same subjects. Baron von Ettingshausen has also published two lists purporting to be complete enumerations of the species from Sheppey and from Alum Bay. For reasons which will be apparent, I cannot help regretting that these lists were compiled and published; but, nevertheless, I intend as far as possible to retain the names given, though they were unaccompanied by descriptions. Setting these two lists apart for the present, we find the following as the number of species that had been more or less described:—

From the Thanet beds	3
„ the Reading beds	9
„ Sheppey	108
„ Alum Bay, &c.	43
„ Bournemouth (deducting those not peculiar)	11
Bovey Tracy	50
Upper Eocenes	13
Mull	9
Antrim, about	16
Total	262

making a grand total of 262 species, not a tenth part of which, I anticipate, will survive a rigorous examination. This was the state of our knowledge of the subject when, in 1878, I was asked to assist in the preparation of a monograph on the Eocene flora, in conjunction with Baron von Ettingshausen, who was to be responsible for the Palæontological work, while I assisted in translating and otherwise.

Our co-operation did not survive the first volume, for I speedily found that my views as to what were satisfactory data, not only on which to found new species, but to identify old ones, were at variance with the Baron's.

I ventured, however, to take the liberty of revising the species in the first volume before closing it, and then intimated to my friend Professor Wiltshire that, if desired, I would endeavour to continue the work alone or, alternatively, relinquish it.

I am very glad it was not decided to relinquish it, although a heavy burden fell on my shoulders, and one which I felt the greatest possible diffidence and hesitation in undertaking. Since then the study of only one group of plants—the Gymnosperms—has been the serious business of the past three years; for not only have I had to study, but in the majority of cases to find the specimens as well. A comparison of the *Coniferæ* known to occur in our Tertiaries before the publication of my Monograph and since will indicate the extent of progress that I trust will be made if I am able to continue the work.

British Eocene Coniferæ described by various Authors.

	Status in Palæontogr. Soc. Monograph.
Cupressinites globosus, Bow.	Not believed to be Coniferous.
" *elongatus* "	
" *recurvatus* "	
" *subfusiformis*, Bow.	
" *curtus*, Bow.	United as *Callitris curta*.
" *Comptoni*, Bow.	
" *crassus* "	
" *thujoides* "	
" *subangulatus*, Bow.	
" *corrugatus*, Bow.	Not believed to be Coniferous.
" *sulcatus* "	
" *semiplotus* "	
" *tesselatus* "	
Cupressites taxiformis, Ung.	*Cupressus taxiformis*.
Sequoia Couttsiæ, Heer.	*Athrotaxis Couttsiæ*.
Sequoia Hardtii, "	*Sequoia Tournalii*.
Taxites Campbelli, Forbes.	*Taxus Campbelli*.
Cupressites elegans, De la Harpe.	*Podocarpus elegans*.
Pinites macrocephalus, Lindl. & Hutton.	*Pinus macrocephala*.
Pinites ovata, id.	*P. ovata*.
P. Bowerbankii, Bow.	*P. Bowerbankii*.
P. Dixoni, Bow.	*P. Dixoni*.
Pinus Plutonis, Baily.	*P. Plutonis*.
Cupressites MacHenrii, Baily.	*Cupressus Pritchardi*.
Sequoia Du Noyeri, Baily.	*Cryptomeria Sternbergii*.

List of British Eocene Coniferæ appearing in the Palæontographical Society's Monograph.

Callitris curta, Bow.	**Athrotaxis subulata*, New.
**Callitris Ettingshauseni*, New.	**Sequoia Tournalii*, Brong.
**Libocedrus adpressa*, New.	*Sequoia Shrubsolei*, New.
Cupressus taxiformis, Ung.	*Ginkgo(?)eocænica*, Ett. & Gard.
**Taxodium Europæum*, Brong.	*Ginkgo adiantoides*, Ung.
**Taxodium eocænum*, New.	*Podocarpus eocænica*, Unger.
Athrotaxis Couttsiæ, Heer.	*Podocarpus elegans*, De la Harpe.

Podocarpus argillæ-Londinensis, NEW.
Podocarpus Campbelli, NEW.
Podocarpus (?) *incerta*, „
Araucaria Gœpperti, Sternb.
Pinus macrocephala, Lindl. & Hutton.
Pinus ovata, id.
Pinus Prestwichii, NEW.
Pinus Dixoni, Bow.
Pinus Bowerbankii, Bow.
Pinus Plutonis, Baily.
**Pinus Bailyi*, NEW.
**Tsuga Heerii*, „
Cupressus Pritchardii, Gœpp.
Cryptomeria Sternbergii, „
**Taxus Swanstoni*, NEW.
Taxus Campbelli, Forbes.
Doliostrobus Sternbergii, Marion.

In this list there are twenty-eight species, fourteen of which are entirely new to science, those marked * being only known through my own collecting. Four other most important *Coniferæ* were previously unrecognised in Britain, these being *Cryptomeria Sternbergii*, *Araucaria Gœpperti*, *Doliostrobus Sternbergii*, and *Taxodium Europæum*. Many of the remainder have been defined with greater precision, especially the Irish species of *Pinus* and the English and Irish species of *Cupressus*, of both of which fruits are for the first time discovered. The true nature of other well-known *Coniferæ* is also recognised, such as that of the supposed *Sequoia Couttsiæ*, ascertained to be an *Athrotaxis*, and the Alum Bay *Cupressites*, found to be a *Podocarpus*. Finally, a number of useless species are suppressed.

Ettingshausen, in the list of Sheppey fossils already referred to, admits the following:—

Callitris curta, Bow.
C. Comptoni, „
Solenostrobus subangulatus, Bow.
S. corrugatus, Bow.
S. sulcatus, „
S. semiplotus, „
Hybothya crassa, Bow.
Cupressinites globosus, Bow.
Cupressinites elongatus, „
C. recurvatus, Bow.
C. subfusiformis, Bow.
Sequoia Bowerbankii, E. & G.
Pinus Sheppeyensis, „
Salisburia eocænica „

The only species which I am able to admit are the first and the last on the list, but I add a new *Callitris*, *Podocarpus*, *Athrotaxis*, and *Sequoia*. Similarly in the list of the Alum Bay Flora the following occur:—

Glyptostrobus Europæus, Brong.
Callitris curta, Bow.
Cupressinites globosus, Bow.
Sequoia Langsdorfii, Brong.
Sequoia Couttsiæ, Heer.
Podocarpus eocænica, Ung.

I am thoroughly acquainted with the specimens on which the above are based, and I do not think they afford satisfactory grounds for supposing these *Coniferæ* to occur at Alum Bay. The beds there are singularly poor in *Coniferæ*, and all the known specimens of true Conifers from them belong to a single polymorphic species, which the attached fruit shows to be *Podocarpus elegans*.

I trust that the results attending the expenditure of the grant we have been favoured with may be considered satisfactory, and these I now proceed to detail.

Bracklesham Flora.—Two visits have been made to Selsey. The beds, it is well known, are marine, but a few terrestrial fruits are from time to time procured from them. I have been particularly anxious before

completing my work this autumn on *Coniferæ* for the Palæontographical Society to procure fresh specimens of the Pine Cones for which the Bracklesham beds are celebrated. Only the higher beds of the series near to Selsey were well exposed on both visits, whilst the cones are found lower down in the series towards the middle of the bay. A local collector has, however, promised to procure specimens when next the proper beds are uncovered.

I was able to make a large collection of fossil shells while looking for plants, which, being from the highest beds, are less known, and are interesting as illustrating the passage from the Bracklesham to the Barton Fauna, which is more gradual, I think, than is supposed. The surface of one of these beds is dotted over with fossil *Posidonias*, a marine monocotyledonous plant identical with the species now inhabiting the Mediterranean. It had not been previously recorded as a British fossil, though another species is abundant in the contemporary beds of the *Calcaire grossier* of the Paris basin.

In our species the rhizomes radiate from a centre, whilst in the French and other European fossil species they are long and branching. They are found among beautiful *Tellina* shells, preserving, to a large extent, their banded colours. The only other fossil plant to record here is a *Nipadites*, which, unlike those of the Bournemouth beds, is large, flattened, and oval.

Reading Beds.—A considerable portion of the grant has been expended in working these beds with, I am pleased to report, the happiest results. The flora is found in the Katesgrove pit, on the banks of the Kennet, immediately beneath the mottled clay. The matrix is a fine porcelainous fuller's earth interstratified with sand, and the beds seem very local. The limit of the pit being reached it is not probable that any part of the beds will be exposed for long.

I have illustrated a beautiful specimen, one of several, of *Anœmia subcretacea*, Sap., from these beds. This Fern is highly characteristic of the lower Eocenes in France, but had only previously been found in the middle Bagshot beds of Bournemouth in this country. I have also illustrated another Fern (?) from these beds, of which I have only as yet found a small fragment. The figures are therefore taken from specimens found many years ago by Professor Prestwich. Other valuable additions to the Reading Flora are some splendid specimens of a Conifer, which I can see no ground for distinguishing from *Taxodium heterophyllum* of China. As these finds will be included in the Palæontographical volume for the present year, I need only say regarding them that *Taxodium* has been hitherto regarded as an almost exclusively Miocene plant. Another interesting specimen from Reading is a pine leaf of two needles, about the size and substance of those of *P. maritima*, the first pine foliage, I believe, ever found in the English Eocene. One leaf bed is almost wholly made up of leaves of *Platanus*, and a bed above is fairly sprinkled with fruits of the same. Fruits are very abundant, and include four kinds of leguminous pods, and there are many flowers. The variety among the leaves is relatively smaller, but all are well marked, and I expect to identify them easily by help of the fruits and flowers. As a result of this work the Reading Flora no longer appears so completely distinct from that of Bournemouth.

Woolwich Beds.—I regard these as thoroughly distinct in age from those of Reading. I have not found, in the course of two visits paid

for the purpose, any bed worth collecting from, though I think such must exist at Lewisham. I figure the crozier and venation of a very characteristic *Lygodium* from a bed of almost fœtid clay crowded with remains of rush, with which this Fern seems mingled in some profusion. I also figure a better specimen picked up at Croydon, and part of a new *Pteris* from the same. Professor Prestwich has the same *Lygodium* from Counter Hill, and also, I think, from another locality near Woolwich; so that it appears to be characteristic of the Woolwich beds.

Studland Beds.—With Mr. Keeping's help and other assistance we were able to reach a leaf bed in the Lower Bagshot at Studland, and to obtain a great number of specimens, nearly all of which are quite new to me. They are mostly dicotyledonous leaves and fruits, which will require time to determine. There are no Coniferæ among them, and I am only able to add one Fern—a *Lygodium*, very near to that of Bournemouth—to the *Chrysodium Lanzæanum* procured abundantly by me ten years ago in a different bed at the same locality.

Hordwell Beds.—Nothing much has been added to the collection made by myself and Mr. Keeping last year, when the perfectly preserved specimens of *Athrotaxis Couttsiæ* were found, our visit this year having been at too dry a season. I have, however, to add *Salvinia* to the flora, not previously found fossil in England, and exclusively confined to the Miocene in Austria and Switzerland.

Barton Beds.—Dry weather made our search for plants unsuccessful here, except for the discovery of a new species of *Pine* from Highcliff, quite unlike those hitherto found at Bracklesham. As the Stour and Avon no longer pass along the base of Highcliff, and the sea has receded there, the beds are rapidly assuming an angle of repose, and becoming deeply buried under *débris*, so that some of them are no longer visible except by making excavations. Being accompanied by Mr. Keeping, who knows the ground thoroughly, we delayed a few days to take complete sections and measurements of all the beds, which we hope to publish jointly with complete lists of the fossils peculiar to each. Though the Barton series is one of the most interesting of our Eocene formations, the detailed bedding has not been worked out like that of the Bracklesham series below and the Headon series above, and the greatest misconceptions seem to prevail as to the number of species of fossils that it contains.

Bournemouth Beds.—Fine series of leaves were obtained this year by Mr. Keeping and myself, the most noteworthy of which are some specimens of *Godoya*, which exceed any I had previously seen. I have illustrated a new and very distinct species of *Adiantum*, a fragment of what may be *Gymnogramma*, and a tufted group of *Polypodium* leaves, which seem to be different from either of the species previously recorded.

The London Clay.—Mr. Shrubsole has kindly sent me some of the best of the fruits that have been found. I have spent much time in endeavours to electrotype these, but I cannot say that, so far, the results have been quite satisfactory. It seems likely, however, that the solution of how to preserve them in an accessible manner will be found in this direction. The experiments I have made would take long to recount, and, though I have found it easy to preserve them out of liquid in a uniformly dry atmosphere, no preparation yet discovered will save them if exposed for a few months to damp air. I have not made any complete studies of them yet, but they promise to afford results of the highest value.

Among a few recognised is the very unmistakable seed of *Verschaffeltia*, a genus of Palms from Seychelles, quite new to fossil floras.

Gurnet Bay Beds.—By the kindness of Mr. A'Court Smith, who has been at great pains to despatch to me from time to time selections from his collection for examination, I have been able to study this flora at leisure during the spring. As a result, I ascertain that another Fern rivals *Anœmia subcretacea* in range, *Chrysodium Lanzœanum*, which extends from the Lower Bagshot upwards into the Bembridge beds. The plants are as a rule dreadfully macerated and chopped up. Among them are small fragments of a *Gleichenia*, which, though not very beautiful, is a very important Fern, coming from the horizon. By far the most important discovery, however, is that of *Doliostrobus*, the first really extinct Conifer that I have met with in British Eocenes. It belonged to the tribe of *Araucarieæ*, and its identification has been thoroughly confirmed by correspondence and the interchange of specimens with Dr. Marion, the well-known botanist of Marseilles. Its description will appear in the forthcoming volume of the Palæontographical Society. A visit to Gurnet Bay will be necessary in order to complete my investigations into this flora.

It is certain that during the Eocene period, as the temperature increased from the base upward to the Middle Bagshot, when the maximum of heat seems to have prevailed, there was a tendency for the plant world to move northward. It is equally certain that in the later half of the Eocene as the temperature began to decrease the movement was in the opposite direction, and we find in the European Miocenes of Switzerland and Italy a number of plants that at an earlier period were growing in the far north. In the Bembridge beds we should expect to find many plants of the Lower Eocenes reappearing that are absent in the Middle Eocenes. Two of the Reading plants reappear in the very limited flora of Hordwell, and two of the Antrim plants in that of Gurnet Bay and Hempstead. Trifling such facts appear, but they have their significance. No such forms occur among the thousands or tens of thousands of plant remains brought from Bournemouth; and we may feel quite certain that they were not comprised in our flora of that date. The moment the Hordwell Beds are searched, and among the first plants obtained from them, are two Reading species. There are of course in a flora many plants, in addition to those thoroughly at home, which are near their limits of heat and limits of cold. Those that were capable of supporting much more heat might have maintained their ground throughout the whole Eocene period, whilst of the rest that migrated some would come back with each successive decrease of temperature, while others might never again find conditions suited to them. Mere superficial observations are of no use in this study, and immense collections and minute comparisons must still be made if our knowledge of Eocene plants is ever to be commensurate with the importance of the subject.

Explanation of Plates.

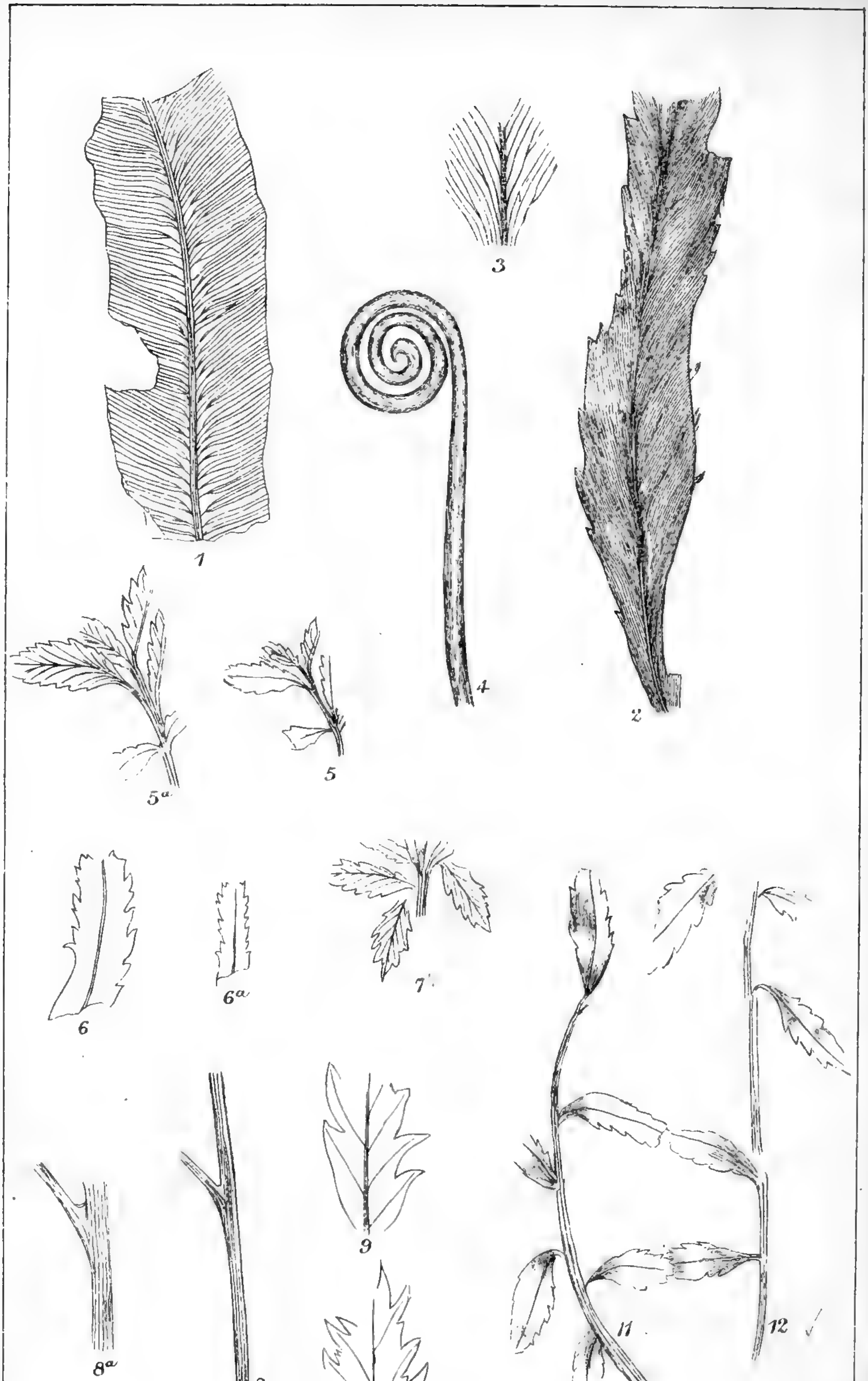
Plate I.

Anœmia subcretacea, Saporta.—Reading Beds, Reading.—This fern is essentially characteristic of the older Eocenes, and even pre-Eocene, rocks. A Fern hardly distinguishable from it appears in the Cretaceous rocks of Aix-la-Chapelle, and other localities in Europe and Greenland. It is found in the old Eocene of Sézanne, in the Paris basin, and in the west of France, and in

Lower Eocene Ferns.

Spottiswoode & Co. Lith. London

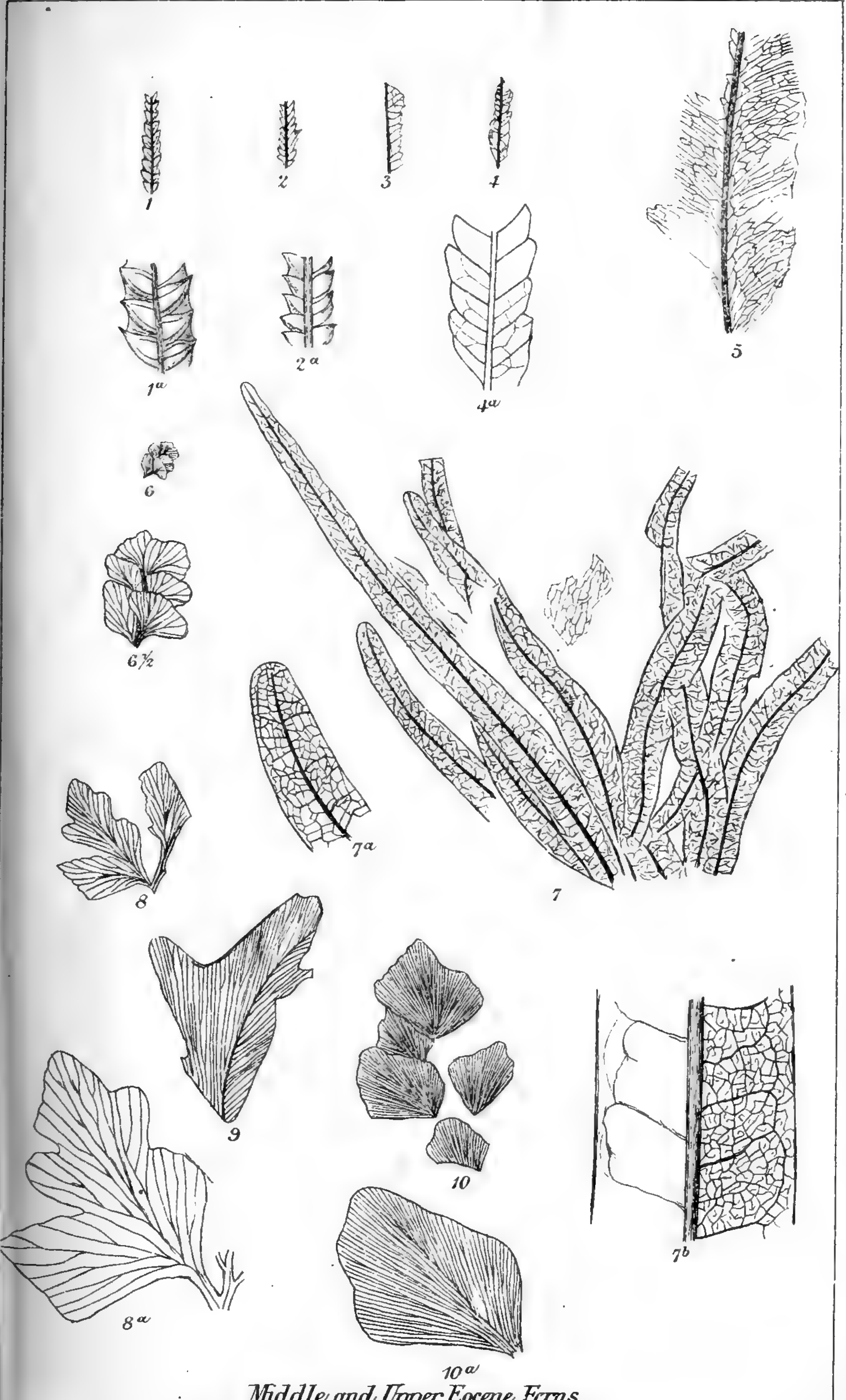
Illustrating the Report of the Committee on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom.



Lower Eocene Ferns.

Spottiswoode & Co. Lith. London

Illustrating the Report of the Committee on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom.



Middle and Upper Eocene Ferns.

Spottiswoode & Co. Lith. London.

[Il]lustrating the Report of the Committee on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom.

the lowest stage of the Lignitic of America. It is not uncommon in the Bournemouth beds, both at Bournemouth and at Branksea Island, but had never previously been found fossil in any of our Lower Eocenes, so that its discovery at Reading is important. It seems not to have extended beyond the Middle Eocenes, to have always been a relatively northern form, and to be now extinct.

PLATE II.

Fig. 1. Fragment of a feather-veined Fern from the Woolwich beds of Croydon. The form is new to our Eocenes, but too fragmentary to be determined. It may be an *Acrostichum* or *Pteris*.

Fig. 2. *Lygodium Prestwichii*, Et. and Gard. sp.—From the Woolwich beds, Croydon; figs. 3 and 4 from Woolwich. A small fragment of this was originally figured by Professor Prestwich in the 'Quart. Journ. Geol. Soc.,' vol. x. p. 156, pl. III. fig. 6. We thought it might be a *Pteris*, not having examined any original specimen, but did not make any definite determination, beyond the opinion that 'there is no particular reason to suppose it to be a *Pteris*; but in the absence of contradictory generic characters we have thought it convenient to consider it as belonging to that genus.' ('Brit. Eocene Flora,' vol. i. p. 53.) I have since examined Professor Prestwich's specimens, and obtained others myself from Croydon and from Woolwich. The pinna was simple or cleft into two or more lobes. The veins are free, and diverge at a sharp angle from the midrib, are crowded, and fork once or twice. The margin is irregularly toothed, the teeth being the bases of fertile segments of the frond, which look as if easily removable by rubbing or maceration. It is perfectly indistinguishable from *Lygodium japonicum*, Sw., an inhabitant of Japan and Hong Kong, Ceylon, Java, the Philippines, &c., of the section Eulygodium. It is quite distinct from the Bournemouth *L. Kaulfussii*, and its determination is a great acquisition to our flora. It is undoubtedly the *Pteris pseudopennæformis*, Lesq., from the first stage of the American Lignitic, and may be identifiable with other European species.

Fig. 3 represents some venation enlarged.

Figs. 5 to 12 represent specimens from Reading in Professor Prestwich's collection. The hard striated stipes, and the cutting and venation of the leaf, are very fern-like, the latter suggesting segments of *Asplenium Thunbergii*; but the straggling growth is rare among Ferns, though possessed by some species of *Acrostichum*, *Anæmia*, and others. I have met with nothing living resembling it, and if a Fern, it is now completely extinct.

Figs. 5*a*, 6*a*, 8*a*, 9, 10 are enlargements, and the rest natural size.

PLATE III.

Figs. 1 and 2. Small fragments of a *Gleichenia* from the insect beds of Gurnet Bay. The venation is very obscure, the mid-rib strong, the texture coriaceous. The specimens are interesting as marking the first appearance in the English Eocenes of a type of Fern that abounded in the Cretaceous beds of Europe and the Eocenes of Antrim and Greenland.

Figs. 1*a* and 2*a* are enlarged.

Figs. 3 and 4 seem fragments of dicotyledonous leaves, shrivelled, and perhaps eaten by insects, but superficially resembling the *Gleichenia*.

Fig. 5. Specimen of *Chrysodium Lanzæanum* from Gurnet Bay. This Fern first appears in the Lower Bagshot of Studland, and maintains its ground through the whole of the Bournemouth series. It again appears in diminished size in the Hordwell beds and the Bembridge beds, and is identical with a still living and widely distributed tropical Fern, *C. aureum*.

Fig. 6. Fragment of Fern from Gurnet Bay. The pinnules are very minute, and are like those of *Gymnogramma flexuosa*, Desv., as well as species of *Lindsaya*, *Microlepia*, &c. It is too small for determination. All the above are lent by Mr. A'Court Smith.

Fig. 7. *Phymatodes polypodioides*, Ett. and Gard., from Bournemouth. This appears an undoubted Polypodium belonging to the section *Phymatodes*. The fronds are far longer and more linear than those of *P. polypodioides* of Bournemouth, yet it seems hardly possible to separate it as a distinct species. The bases of attachment are, most unfortunately, absent in all, but their disposition almost

proves that they were fronds tufted on a rhizome and not lateral pinnæ, as I had surmised from the isolated specimens previously known. Their resemblance to the living *P. geminatum* and other tropical American species is very striking.

Fig. 7*a* is enlarged twice, and 7*b* four times.

Fig. 8. Fragment of a Fern from Bournemouth, very like *Gymnogramma aurea*, the Golden Fern of our conservatories, but with larger pinnules. It might prove to be an *Adiantum* or *Lindsaya*, but the veins are relatively wide apart. Though in beautiful preservation the fragment is too small for determination.

Fig. 8*a* is part of the same enlarged twice.

Fig. 9. Fragment of *Lygodium* from the Lower Bagshot, Studland. Though like the Bournemouth *L. Kaulfussii* the veins are much closer, and it seems intermediate in form between that and the Woolwich species. No Lygodium of this age was previously known.

Fig. 10. *Adiantum* from Bournemouth. The rachis has somehow disappeared, leaving the pinnæ undisturbed in their relative positions. It is quite distinct from any fossil *Adiantum* previously known, and is identical with *A. flabellulatum*, Linn., of Ceylon, Japan, Hindostan, and the Malayan Peninsula and Islands. The unique impression is exceedingly fine, delicate, and colourless. The enlargement, fig. 10*a*, has, I fear, not quite included the margin, which is very slightly denticulate, and too much mid-rib is shown, for most of the veins actually diverge from the base, repeatedly forking, so that their relative distances are maintained to the margin. They are more crowded than in another Bournemouth maidenhair, *A. apalophyllum*.

These Ferns add to the large number of plants already known that migrated from our latitudes after the Eocene, and are now found established in Western Asia and Central America. Though fragmentary, most of them are new, and, being omitted in our Monograph, deserve to be recorded.

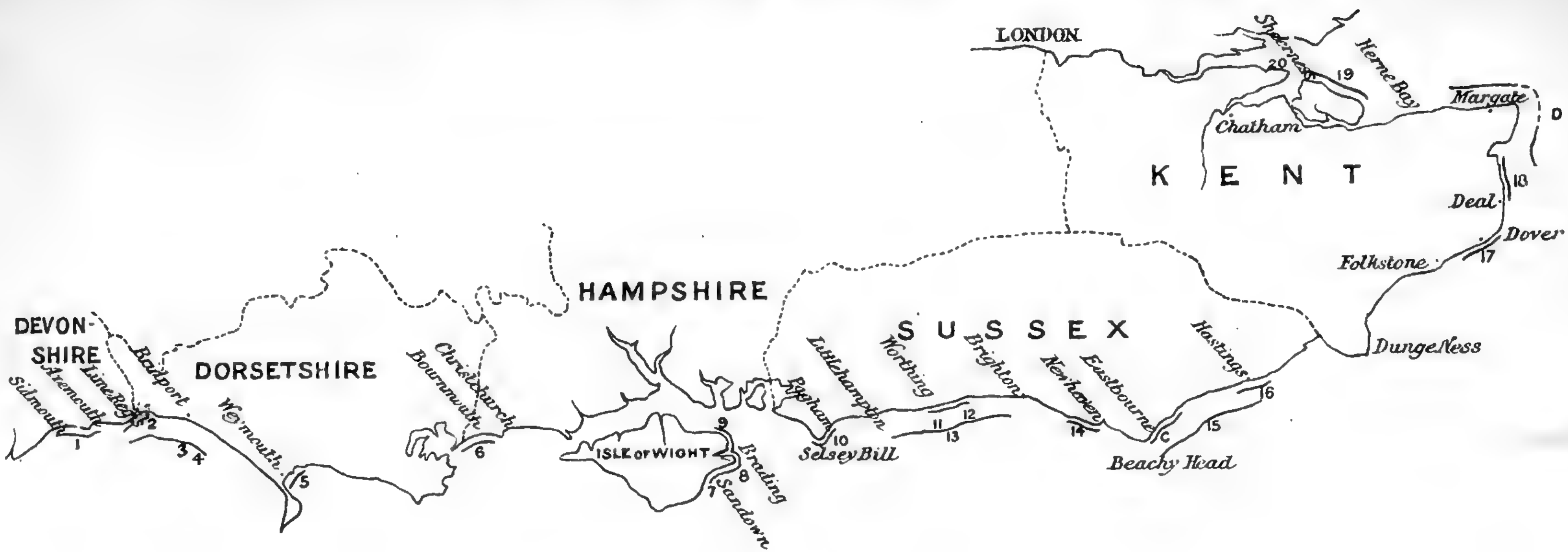
Report of the Committee, consisting of Messrs. R. B. GRANTHAM, C. E. DE RANCE, J. B. REDMAN, W. TOPLEY, W. WHITAKER, *and* J. W. WOODALL, Major-General Sir A. CLARKE, Sir J. N. DOUGLASS, Captain Sir F. O. EVANS, Admiral Sir E. OMMANNEY, Captain J. PARSONS, Professor J. PRESTWICH, Captain W. J. L. WHARTON, Messrs. E. EASTON, J. S. VALENTINE *and* L. F. VERNON HARCOURT, *appointed for the purpose of inquiring into the Rate of Erosion of the Sea-coasts of England and Wales, and the Influence of the Artificial Abstraction of Shingle or other Material in that Action* (C. E. DE RANCE *and* W. TOPLEY, *Secretaries*; *the Report edited by* W. TOPLEY.)

[PLATE IV.]

THE importance of the subject referred to this Committee for investigation is universally admitted, and the urgent need for inquiry is apparent to all who have any acquaintance with the changes which are in progress around our coasts. The subject is a large one, and can only be successfully attacked by many observers, working with a common purpose and upon some uniform plan.

In order fully to appreciate the influence, direct or indirect, of human agency in modifying the coast-line, it is necessary to be well acquainted with the natural conditions which prevail in the places referred to. The main features as regards most of the east and south-east coasts of England

SKETCH-MAP *shewing the Districts referred to in the Report.*



Spottiswoode & Co. Lith. London.

Illustrating the Report of the Committee on the Erosion of the Sea coasts of England & Wales.

are well known; but even here there are probably local peculiarities not recorded in published works. Of the west coasts much less is known. It has therefore been thought desirable to ask for information upon many elementary points which, at first sight, do not appear necessary for the inquiry with which this Committee is intrusted.

A shingle-beach is the natural protection of a coast; the erosion of a sea-cliff which has a bank of shingle in front of it is a very slow process. But if the shingle be removed the erosion goes on rapidly. This removal may take place in various ways. Changes in the natural distribution of the shingle may take place, the reasons for which are not always at present understood; upon this point we hope to obtain much information. More often, however, the removal is directly due to artificial causes.

As a rule, the shingle travels along the shore in definite directions. If by any means the shingle is arrested at any one spot, the coast-line beyond that is left more or less bare of shingle. In the majority of cases such arresting of shingle is caused by building out 'groynes,' or by the construction of piers and harbour-mouths, which act as large groynes. Ordinary groynes are built for the purpose of stopping the travelling of the shingle at certain places, with the object of preventing the loss of land by coast-erosion at those places. They are often built with a reckless disregard of the consequences which must necessarily follow to the coast thus robbed of its natural supply of shingle. Sometimes, however, the groynes fail in the purpose for which they are intended—by collecting an insufficient amount of shingle, by collecting it in the wrong places, or from other causes. These, again, are points upon which much valuable information may be obtained.

Sometimes the decrease of shingle is due to a quantity being taken away from the beach for ballast, building, road-making, or other purposes.

Solid rocks, or numerous large boulders, occurring between tide-marks, are also important protectors of the coast-line. In some cases these have been removed, and the waves have thus obtained a greater power over the land.[1]

The Committee has during the past year received several Returns relating to the south and east coasts of England. Those relating to the coast south of the Thames are here printed, with the exception of one by Mr. K. McAlpin on Pembrokeshire.[2] As the amount of change on the rocky coast here described is small, and as the Return is accompanied by several photographs—without which illustrations its value would be much decreased—the publication of this is deferred.

The other Returns in hand are:—J. Bateman, Estuary of the Colne[2]; P. S. Bruff, R. Deben to near R. Colne[4]; Maj. A. G. Clayton, Great Yarmouth[2]; W. Teasdell, Aldeburgh to Cromer[3]; A. C. Savin, Weybourne to Happisburgh[4]; Clement Reid, Weybourne and Palling[4]; C. Fox-Strangways, Scarborough[4]; Lieut.-Colonel Melville, Northumberland coast.[2]

The thanks of the Committee are especially due to Major-General Sir A. Clarke, who has instructed the Officers of the Royal Engineers

[1] The foregoing paragraphs, giving a general statement of the objects of this Committee, are reprinted from the preliminary Report of last year.

[2] Supplied through Sir A. Clarke. [3] Supplied through Mr. J. B. Redman.

[4] Supplied through Mr. W. Topley.

stationed around the coast to supply the Committee with such information as they may possess or may be able to obtain. Further returns are expected from the same Department and from other official sources; the Committee therefore think it best to defer any general Report until more complete information is obtained.

The Report by Mr. J. B. Redman on the South-Eastern Coast so fully sets forth the work of the Committee, and the importance of the inquiry referred to it, that this is now printed.

The Report by Mr. G. Dowker on the Coast of East Kent gives an account of the changes of the coast in this district, changes which are of especial historical importance and interest.

Mr. Whitaker has drawn up a List of Works on the Coast-Changes and Shore-Deposits of England and Wales, which will be of great service to the Committee and to those who may assist in the inquiry. In order to make this as complete as possible, it has been brought down to the date of publication.

The various Reports—General and Local—are printed on the authority of the respective authors. The Full Report of the Committee is deferred.

The Committee would again ask for the assistance of any who, by long residence or by other means, have special knowledge of changes on any part of the English and Welsh coasts. Printed forms of questions can be obtained from the Secretaries or from any member of the Committee.

Copy of Questions.

N.B.—Answers to these questions will in most cases be rendered more precise and valuable by sketches illustrating the points referred to.

1. What part of the English or Welsh Coast do you know well?

2. What is the nature of that coast?

- **a.** If cliffy, of what are the cliffs composed?
- **b.** What are the heights of the cliff above H.W.M.? Greatest; average; least.

3. What is the direction of the coast-line?

4. What is the prevailing wind?

5. What wind is the most important—

- **a.** In raising high waves?
- **b.** In piling up shingle?
- **c.** In the travelling of shingle?

6. What is the set of the tidal currents?

7. What is the range of tide?

- (1) Vertical in feet. (2) Width in yards between high and low water.
- (**a**) At Spring tide; (**b**) at Neap tide?

8. Does the area covered by the tide consist of bare rock, shingle, sand, or mud?

9. If of shingle, state—

- **a.** Its mean and greatest breadth.
- **b.** Its distribution with respect to tide-mark.
- **c.** The direction in which it travels.
- **d.** The greatest size of the pebbles.
- **e.** Whether the shingle forms one continuous slope, or whether there is a 'spring full' and 'neap full.' If the latter, state their heights above the respective tide-marks.

10. Is the shingle accumulating or diminishing, and at what rate?

11. If diminishing, is this due partly or entirely to artificial abstraction? (*See* No. **13**).

12. If groynes are employed to arrest the travel of the shingle, state—

- **a.** Their direction with respect to the shore-line at that point.

b. Their length.
c. Their distance apart.
d. Their height—
(1) When built.
(2) To leeward above the shingle.
(3) To windward above the shingle.
e. The material of which they are built.
f. The influence which they exert.

13. If shingle, sand, or rock is being artificially removed, state—
a. From what part of the foreshore (with respect to the tidal range) the material is mainly taken.
b For what purpose.
c. By whom—Private individuals. Local authorities. Public companies.
d. Whether half-tide reefs had, before such removal, acted as natural breakwaters.

14. Is the coast being worn back by the sea? If so, state—
a. At what special points or districts.
b. The nature and height of the cliffs at those places.
c. At what rate the erosion now takes place.
d. What data there may be for determining the rate from early maps or other documents.
e. Is such loss confined to areas bare of shingle?

15. Is the bareness of shingle at any of these places due to artificial causes?
a. By abstraction of shingle.
b. By the erection of groynes, and the arresting of shingle elsewhere.

16. Apart from the increase of land by increase of shingle, is any land being gained from the sea? If so, state—
a. From what cause, as embanking salt-marsh or tidal foreshore.
b. The area so regained, and from what date.

17. Are there 'dunes' of blown sand in your district? If so, state—
a. The name by which they are locally known.
b. Their mean and greatest height.
c. Their relation to river mouths and to areas of shingle.
d. If they are now increasing.
e. If they blow over the land; or are prevented from so doing by 'bent grass' or other vegetation, or by water channels.

18. Mention any reports, papers, maps, or newspaper articles that have appeared upon this question bearing upon your district (copies will be thankfully received by the Secretaries).

19. Remarks bearing on the subject that may not seem covered by the foregoing questions.

General Reports.

A.—The South-Eastern Coast of England.

By J. B. Redman, F.G.S., M.Inst.C.E.

July 21, 1884.

That the erosion of our south-eastern coasts by the action of wind-waves has been assisted and increased by artificial agency, by removal of material and by the treatment of works of defence in a selfish spirit, unaccompanied by concerted action, resulting in injury to adjoining frontages for the benefit of those operated on, can be copiously illustrated by the records of our public departments, such as the Admiralty, Woods and Forests or Works, the Board of Trade, the War Office, and the Trinity Corporation, as well as by those of nearly every harbour board, river conservancy, or local drainage and sewage authority. And this fact is pourtrayed in a special literature of its own; the Blue Books of the House of Commons, for the various tidal harbours' reports, inaugurated by the persistent agitation of the late Joseph Hume, M.P., as well as those on harbours of refuge, lighthouses, and shipping, give incidentally numerous isolated cases showing how much this really imperial question has been overlooked or confused by a division of authority; and the struggles with lords of the manor, illustrated by a number of well-known cases, add additional exemplification.

The legal aspect of this question has been recently ably treated by a republication of Hall's 'Essay on the Rights of the Crown in the Sea-shore,' by Richard

Loveland Loveland, of the Inner Temple, in 1875; and this work shows well the imperial character of the inquiry deputed to the British Association Committee on the Erosion of the Sea Coasts of England and Wales.

We are told in this essay, on p. 2, that 'this dominion or ownership over the British seas, vested by our law in the king, is not confined to the mere usufruct of the water and the maritime jurisdiction, but it includes the very *fundum* or soil at the bottom of the sea.'

The effect resultant on the frequent piercing of our sea littoral by estuaries, creeks, and rivers is graphically described on p. 3, indicative of the extent of territory involved. 'This dominion not only extends over the open seas, but also over all *creeks, arms of the sea, havens, ports, and tide rivers*, as far as the reach of the tide, around the coasts of the kingdom. All waters, in short, which communicate with the sea, and are within the *flux* and *reflux* of its tides, are part and parcel of the sea itself, and subject, in all respects, to the like ownership.'

'Grants of the sea-shore by the king' are treated on at p. 14, and 'As to the claims of lords of manors to the sea-shore' at p. 17.

'As to digging for sand, &c.,' we have, at p. 92, the following apposite opinion:—'With regard to the "constant and usual fetching of sea-sand, seaweed, and gravel, between the high-water and low-water mark, and licensing others so to do; and embanking against the sea, and enjoyment of what is so *inned*"—these, it must be admitted, are all acts likely to be done by the owners of the soil, and they afford colour that he who does such acts is the owner; but these acts may be usurpations or intrusions on the king's ownership, and *primâ facie* are so.'

The sea-coast margin is at p. 108 divided into three categories, the treatise saying that, 'as to alluvion and derelict land, land gained from the sea is of three kinds:

'1st. *Per alluvionem*, alluvion, or land washed up by the sea.

'2nd. *Per relictionem*, derelict land, or land left dry by the shrinkage or retirement of the sea.'

And at p. 109 we read: 'The law on this part of the subject is laid down by Blackstone in these words:—"As to lands gained from the sea, either by *alluvion, i.e.*, by washing up of sand or earth, so as in time to make *terra firma*; or by *dereliction*, as when the sea shrinks back below the usual water-mark, in these cases the law is held to be that, if this gain be by little and little, by small and *imperceptible* degrees, it shall go to the owner of the land adjoining, for 'de minimis non curat lex;' but if the alluvion or dereliction be sudden and considerable, the land shall go the king, as lord of the seas."'

The land gained from the sea in the third category would be that from which the waters had been excluded by artificial works of embanking and drainage, generally applicable to salt marshes of silty deposit gradually risen to the height of neap-tide flow, but only covered by spring tides.

It is curious to find Blackstone and his commentators talking of these salt-slob lands, which, by their gradual accretion, have risen above the influence of all but great tides, as *dereliction* caused by the shrinkage of the sea below its usual level, whereas the converse is the case, the surface gradually rising and shutting out the tide by its own proper operation. The fact that O. D. is mean level of the sea is sufficient illustration of Blackstone's physical inaccuracy in this special instance.

As regards the wholesale removal of shingle and boulders from marine spits and moles, it is only necessary to refer to such cases as the quarrying of cement stones from the foreshores on either side of Harwich, from the Beacon cliff to the southward, and from the Felixstow cliffs to the northward, only stopped by the persistent efforts made by Captain Hewett's successor in the North Sea Survey, the late Admiral Washington, and others. For illustration of this pernicious practice and the deplorable results frequently entailed this case suffices. Again, on the northern side, the indiscriminate removal of shingle from the northern breakwater of Harwich harbour (Landguard Point) for ballastage by the lord of the manor has been the fruitful source of litigation. Similar results from similar practices at Spurn Point, at the mouth of the Humber, have been entailed. In effect, this natural shingle mole, defending the entrance to the most important harbour on our eastern coast, was nearly breached in consequence.

Next to the removal for ballastage, the most fertile cause is removal of material for road-making and for building purposes, and when in the neighbourhood of a large town this becomes, from the enormous quantity removed in the aggregate, sufficient to tell eventually on the oscillating natural foreshore protection. Take the case of Hastings: for the last half-century there has been a constant draw on the material

for such purposes. The quantity used must be enormous, and in effect the new portion of the town may almost, without figure of speech, be described as in a large measure built out of the sea. About 1836 Hastings was separated from St. Leonards by a small marshy bottom, with a rill of water running through it, called the 'Priory Marsh,' and during that year the sea was excluded by the erection of a vertical stone wall joining the esplanade terraces, and the two towns became what it is now, one big town. Since that wall was erected the shingle in front of it has, from various causes, become much attenuated, the groynes destroyed, and the sea has, it is said, in places got under the sea walls. So great has been the loss in the bay to the eastward, where is situate the old portion of the town, the fishermen's quarter, that a general exodus of that industry to Rye, or elsewhere, has been threatened.

A second groyne is being constructed from the base of the East Cliff (where a similar work formerly existed) at a very great cost, in order to promote accumulation of shingle along the Hastings frontage, and to bring about again the old state of things.

The argument made use of by many owners of property here, as elsewhere, to the effect that removal of shingle for building purposes must be inappreciable (as, however great the abstraction for such purposes, millions of tons renew the shore after a change of wind) is made in evident forgetfulness or ignorance of the fact that these abstractions from and renewals to the natural 'fulls' of beach, alternately reduce and increase what is a circulating medium of defence, moving in opposite directions up and down channel, with a preponderating movement up channel, due to prevalence of south-west winds, and that such a constant drain on a natural defence, however recuperative, must tell in the long run.

The removal of boulders from the foreshore seaward of the summit shingle neap and spring 'fulls,' either for road-making or for manufacturing purposes, not only loosens the foreshore, and renders it, thus disintegrated, less able to resist the stroke of the wave, but in many cases, such as the 'Chenies' rock off Sheerness, and the 'Septaria' blocks off Harwich, the material formed natural groynes and breakwaters, and their removal, in reference to shore conservancy, was most suicidal.

Another fertile source of accelerated erosion of a special locality is the erection of a close pier for a harbour entrance, and of large and lofty groynes for accumulating shingle, looking only to the protection of an isolated frontage, and without reference to the attendant abstraction of material to the leeward of such works, from the absolute stoppage of the material on its way to the less favoured locality. The case is parallel to the last, as the oscillating medium is laid under heavier contribution for a favoured locality, and is gradually starved for the neglected neighbour to leeward.

Folkestone may be cited as a principal delinquent of this class, due to the elongation of the close pier to the windward or westward of its harbour, which half a century back was a trap for shingle; and a fisherman's first task in the early morning, prior to that, was to excavate a channel through the newly-arrived shingle to get his boat through and out to sea. The resultant accumulation of shingle to windward forms the tongue of land on which stands the 'Pavilion,' &c.

Now, in 'East Wear' Bay there is an almost entire absence of shingle, and the resultant falls of the chalk undercliff take place at so alarming a rate that the very existence of the South-Eastern Railway is jeopardised. That this action is not due to the Admiralty pier at Dover is shown by the entire absence of shingle to windward of that work, but in its place a remarkable extension of the silty foreshore has taken place, gradually diminishing towards Folkestone. Eastward of Dover we have similar results from the same cause; from the Castle jetty to St. Margaret's the base of the lofty chalk cliff is now washed and abraded by the waves, and the lower *débris* and shingle, forming an undercliff carriage-way into Dover some thirty years back, has now entirely disappeared.

We may be asked to suggest a remedy, but this, perhaps, is beyond the province of this Memorandum; but as regards the old stereotyped plan of building a solid pier out from the shore, for communication therewith from vessels, or for protection of the outfall of a tidal river, it has been suggested that there are numerous cases where a moving beach has to be crossed, that it would be better to commence the solid work altogether seaward of the shingle 'fulls,' and connect it with open piling to the shore, and so as to leave the littoral movement of beach uninterfered with.

As respects groynes, there is hardly a watering-place on our southern coast where they have not become a burning *vexata quæstio* of the day, and, at most of them, illustrate the suggestion made more than thirty years back, that groynes cut

up a shore into a multitude of bays, with a repletion of material on one side and deep water on the other, and would have had a better substitute in a sea-wall that allowed the shingle to pass freely backwards and forwards along its face. Such was the experience with the frontage of Romney Marsh, defended by Dymchurch sea-wall, $3\frac{1}{4}$ miles in length, where the old system of groynes, which cut up the frontage into an interminable number of bays, was abandoned about forty years back in favour of the present stone slope ('Proc. Inst. C.E.' vol. vi., plan and sections).

The system of groynes at Brighton, for some isolated points, appeared to have answered well when the supply arriving at that town of shingle from the westward was uninterfered with, but a change occurs when the system was continued to Hove, or West Brighton, in thickening quantities. The material arriving was a constantly diminishing one, from the fact that the Shoreham Gas Works, erected under an Act of Parliament on the 'live' beach between the harbour and the sea, were found to stand upon a somewhat unstable base, with a fickle sea defence, unless supplemented by artificial works. Groynes on an extended scale were erected, which treated West Brighton in the same ungenerous spirit entertained in former days for Rottingdean, for the sake of and advantage of Kemp Town. The encroachment of the sea to the leeward side of the groynes, on the esplanade lawns, has necessitated the erection of an esplanade wall.

B.—The South-Eastern Coast of England.

By Colonel E. C. Sim, R.E. (Retired).

To the Commander Royal Engineers, Brighton.

55 Lower Belgrave Street, London. Dec. 4, 1884.

Sir,—With reference to War Office Memo. Oct. 23, 1884, and the Minute of the Commander Royal Engineers, S.E. District, thereon, dated Oct. 25, 1884, and enclosure returned herewith, I have the honour to state that as I have been employed as C.R.E. at three stations in the Chatham and S.E. Districts during the last five years, which stations have all more or less been connected with foreshore questions, in which I have taken great interest, as affecting War Department property and rights, I trust I may be allowed (although on the Retired List) to make a few remarks about 'The rate of erosion of the sea coasts of England and Wales, and the influence of the artificial abstraction of shingle and other material in that action,' as mentioned in the circular of the British Association for the Advancement of Science.

With reference to the coast-line from Sheerness to Shellness Point in the Isle of Sheppey, with which I was well acquainted from 1879 to 1882, it would appear that the high land of Warden Point, which is nearly the only cliff in Sheppey, is gradually being undermined by the action of springs and the sea; the débris being more or less conveyed by the tide towards Sheerness, and the limestone-nodules, or lumps from the débris, are collected afterwards by the fishermen and others on the beach, and sold for lime and cement. The coast-line near Leysdown station is being denuded of shingle likewise, and a stone apron erected some years ago near the coastguard station has been washed up and practically destroyed in 1880. The movement of the shingle is from east to west along the estuary of the Thames; and if it were not caught by the Garrison Point Fort, which is protected by strong wooden groynes put down when the fort was erected, my opinion is that the whole of Sheerness would be submerged. The point acting as a breakwater and large groynes 'backs up' the shingle along the whole front of the fortifications, which are also protected by groynes, and so on to Sheerness Marine Town and Cheyney Rock, W. D. property; after which, in my time, the foreshore was so exposed by the absence of groynes and want of care and attention, that it seemed likely the whole of the adjoining lands would be submerged at high tides, the sea-wall or dyke also being ineffective. I am unable to give any exact description of the formation of the cliffs in Sheppey. I believe they are of London Clay (with nodules of impure limestone or septaria), and are from 60 to 80 feet in height. The foreshore of shingle in front of Sheerness and Mile Town extends for perhaps 80 yards at low water. While on this subject, I may as well mention that the southern or right bank of the Medway at Sheerness, from the Royal Dockyard to Queenborough, had also to be protected against the inroads of the sea or river by groynes and dykes, or walls. The 'wash' near Queenborough Pier

was very great, and we constantly had to employ gangs of men in refacing the front and top of the river walls. On the north side or left bank of the Medway, at the Isle of Grain, where the large fort was built for the protection of the entrance to the river, &c., the sea or estuary made great inroads in the foreshore of clay or mud which formed the foot of the glacis of the fort. The sea-walls and groynes built at the point opposite the dockyard at Sheerness had to be constantly repaired and kept in order, or the foreshore would have gone altogether. The action of the sea or estuary in this case, as well as at Sheerness generally, was most effective when the wind was N.E. and the tides high; there was scarcely any shelter from the N.E., the water was driven up with great force over the walls, and the shingle at the groynes was disturbed; and at the great storm during the frost of January 1881, the sluices which should have let the surface-water out were frozen, and the whole of the low-lying ground was flooded and afterwards frozen, which did a great deal of damage to property, and caused much malaria afterwards.

The direction of the groynes generally was N.E. towards the prevailing wind, and the accumulation of shingle to windward was often 6 or 7 feet higher than the other side. There was scarcely any movement of shingle when the wind was westerly and from the south, as the coast-line was well protected by the adjoining banks and shoals. With regard to the abstraction of shingle from the foreshore at Sheerness, no doubt the proprietor of the foreshore at Marine Town used to sell the shingle to builders and others, but as the sea-wall at this place was considerably retired in position, I am not sure that much harm was done in my time. At Garrison Point, inside the line of fortifications, we allowed a small amount of shingle to be taken for building purposes, but only on the river-front. Beyond Cheyney Rock and towards Warden Point, a great deal of shingle was taken away by builders and others to make concrete. My own opinion is that, as a rule, none should be allowed to be taken from Sheerness, as the whole front is really artificially kept up, and the shingle is a very important factor in the matter. Where there is a great accumulation of shingle at groynes it may be allowed, in exceptional cases, to remove shingle for W.D. purposes.

With regard to the coast-line from Folkestone to Dungeness and Winchelsea, with which I was acquainted in 1882 and 1883, I would state generally that the sea is making inroads near Folkestone towards East Wear Bay, caused no doubt by the scour of the sea thrown on the foreshore by the piers of the harbour; but the three towers on the cliff above are not affected thereby. The S.-E. Railway Company are protecting the front of the town near the Pavilion Hotel and Pier, and towards Sandgate many groynes have been constructed. Sandgate Castle has, I believe, been taken over by the S.-E. Railway Company, and I imagine they will protect the foreshore there. The sea-walls at Seabrook and Hythe were much damaged by a gale in 1882, from want of the proper number of groynes; these have, I believe, since been provided by the S.-E. Railway Company.

From Hythe to Dymchurch and Dungeness, as I understand, the Lords of Romney Marsh keep up the canal sluices, sea-walls, groynes, &c., and do it very well; doubtless they prevent shingle from being taken. From Dungeness to Winchelsea the same rule applies, and except where the foreshore of the towers and forts occasionally intervenes, I imagine the whole coast-line is protected by these Commissioners of Levels. The movement of shingle towards Dungeness Point from the westward is very apparent; it is caught up there, and the foreshore is gradually increasing. At one time the sea came up to Winchelsea, Lydd, and New Romney, although they are now a considerable distance inland. I should say that the sea is encroaching a little between Dungeness and Rye, but Rye Harbour is becoming shallower. I do not imagine shingle is allowed to be taken from the foreshore here, except under very careful supervision.

From Winchelsea to Hastings I know but little; except that near Hastings, at Rock-a-Nore Cliffs, one very large stone groyne has been built, and one is in course of construction near the Practice Battery, which effectually keep up the shingle and prevent it going eastward and undermining the cliffs and damaging the Fisherman's Town. The whole front of Hastings and St. Leonards is protected by sea walls and groynes kept up by the local authorities, and I imagine shingle is only allowed to be taken in small quantities for public building purposes. From Hastings to Bopeep and to Bexhill considerable inroads have been made by the sea, and some of the old Martello-towers have gone. The lord of the manor or local authority at Bexhill is building a sea-wall there to protect the front and form an esplanade; but at the neighbouring foreshore west much of the ground has been recently washed away, and until Pevensey Bay

is reached there is no local authority interested apparently in preserving it. The Commissioners of Pevensey Levels are supposed to protect the foreshore from Bexhill towards Eastbourne; a few groynes have been made by them and by the L.B. and S.C. Railway Company, but no great efforts are made to keep up the bank of shingle. The wash or scour from Eastbourne has, I fancy, affected this part a good deal. The whole front of Eastbourne, from the Circular Redoubt to near Beachy Head, is protected by groynes and sea-walls kept up by the town. I understand that the sea has during the gale now raging made another breach in the wall at the east end of Circular Redoubt, Eastbourne. Last year a breach was made and temporarily repaired; but as the Commissioners of Pevensey Levels did nothing to repair their groynes and sea-defences, doubtless the sea has got in behind the W.D. sea wall and has flooded the adjacent land. The local authorities of Eastbourne intended to have taken over this portion, and to have extended their sea-wall along the whole front of the War Department property.

From Beachy Head to Seaford, I am not aware of the state of the coast-line; the high cliffs of chalk, &c., are, I understand, being undermined in places; but I do not think there is much shingle at their foot. From Seaford Head to Newhaven there is considerable beach kept up by groynes and sea wall. An esplanade has also been formed by the Commissioners. On the Newhaven side, under the fort, shingle is allowed to be taken by the Harbour Commissioners to make into concrete, but as the beach is protected by the pier and breakwater, no shingle can pass to the eastward, and no harm is done.

From Newhaven to Rottingdean and Brighton, I fancy the cliffs are being gradually undermined by the action of the sea. There is a shingle beach at Rottingdean which is used by bathers, but I fancy that the scour of the shingle caused by the sea defences of Brighton has denuded the foot of the cliffs between Rottingdean and Brighton of any shingle deposited there. The sea-defences of Brighton in the shape of groynes and sea-walls are of course kept up by the local authorities very carefully, as the importance and popularity of the place depend upon the sea-front. At Hove the recent works designed by Sir John Coode are approaching completion.

From Brighton to Shoreham the 'head' or 'full' of the beach of the peninsula formed by the Aldrington Basin, &c., is, I believe, well kept up. I do not think shingle is allowed to be removed thence. At Shoreham Harbour, to the west of the river Adur, the shingle is taken by the Commissioners from their property under the Redoubt and barged away to Brighton for making concrete at the new sea-defences. Apparently the shingle accumulates as fast as it is taken away. From Shoreham to Worthing, I cannot say that I know much. I believe the 'head' or 'full' of the beach is kept up, and I have never heard of any breaches made by the sea there. At Worthing the local authorities keep up the sea-walls and groynes to form an efficient esplanade and roadway. I do not think that shingle is removed. At Littlehampton the sea-front is protected by groynes and sea-wall, but the foreshore is principally of sand. The shingle lies to the westward of the river Arun, and thence sandhills and dunes form an efficient protection from the inroads of the sea.

At Bognor the local authorities are gradually improving the sea-front with groynes and sea-walls, but I fancy the sea makes many inroads into the foreshore adjacent; shingle should certainly not be removed from this place.

I have the honour to be, Sir,

Your most obedient Servant,

(Signed) E. C. Sim, Colonel.

Remarks on Groynes for Sea Defences.

1. Groynes are indispensable—1st. To check the movements of shingle. 2nd. To assist in forming a 'head' or 'full' of beach. 3rd. To cover the 'tie' or foot of sea-walls with shingle, and prevent them being undermined.
2. They should be directed towards the prevailing dangerous wind.
3. If the coast suffers from both quarters—i.e. S.E. and S.W. winds—land-ties on each side are necessary.
4. Short groynes—say 80 feet long—are better for protecting walls, in my opinion.
5. Long groynes are better for forming 'head' or 'full' of beach.
6. I consider that an 80-feet groyne will protect a part of about 100 feet. If there is much scour they should be *closer*.

7. The great object is to get the *beach* just to fall over the top and accumulate on the leeward side as well as the windward.
8. The Hastings, Eastbourne, and Brighton groynes are good ones; although some at Eastbourne are, in my opinion, too high.
9. If the piles or uprights are long enough, sheeting can always be added afterwards if necessary.

(Signed) E. C. SIM, Colonel R.E., Retired List.

December 4, 1884.

C.—The Erosion of the Sea-Coast between Langney (or Langley) Point and Beachy Head, Sussex.

By F. W. BOURDILLON, M.A., Eastbourne.

The erosion of this part of the coast has been treated of by Mr. J. B. Redman, in the 'Proc. Inst. C. E.,' vol. xi. p. 162, also by the Rev. H. E. Maddock, in a paper read before the Eastbourne Natural History Society in 1875, and published in their Proceedings. But the 'Survey of the Coast of Sussex,' made in 1587, and edited of

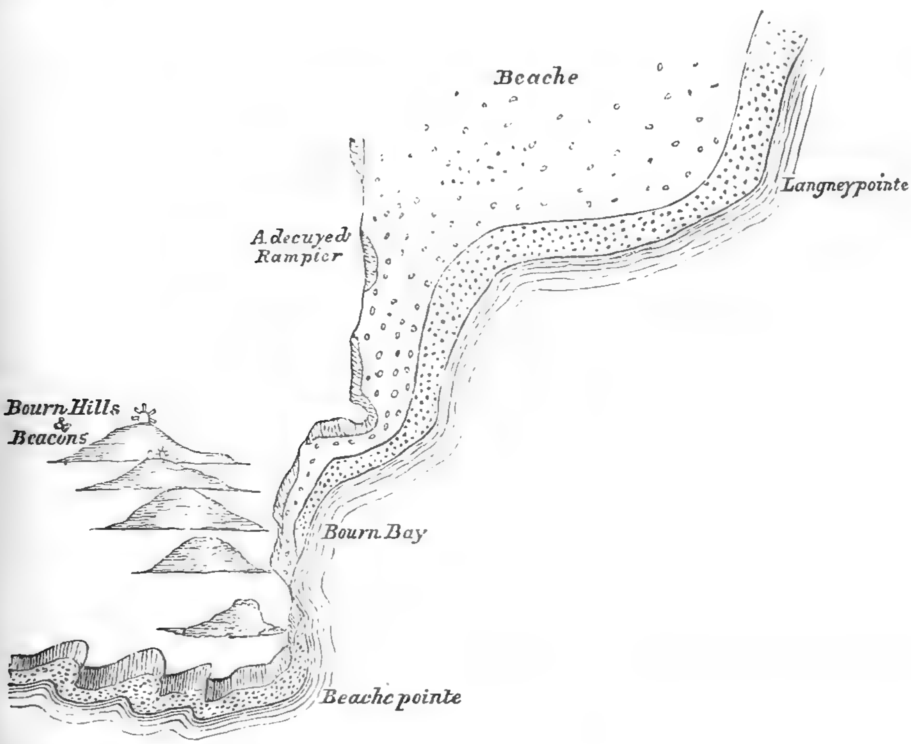


FIG. 1.—The Coast from Beachy Head to Langney Point. (From a survey made in 1587.)

late years by the late M. A. Lower, shows that some of the conclusions arrived at in these papers, touching this part of the coast, may require corrections,[1] especially as regards the Langney shingle beds. This survey (the original of which,[2] on vellum, and in an excellent state of preservation, is in the hands of Mr. Wynne E. Baxter, of Lewes) shows a large tract, marked 'Beache,' where the present shingle beds extend, and

[[1] The conclusions here referred to are confirmed by this Report. Mr. Maddock's paper, was taken from that in the 'Proc. Inst. C. E.,' as regards this part of the coast.—J. B. R., February 1886.]

[2] Another copy is in the British Museum.

even marks 'Langney Pointe,' which, not being marked on Dean Nowell's map, Mr. Maddock assumes not to have been in existence at that date.

It will be best to divide this piece of coast-line into three, as there is a considerable difference in these subdivisions. Going from east to west we have—

(1) The Langney shingle beds, where the shore is composed entirely of shingle in fulls or ridges.

(2) The low cliffs from the sea houses ('Splash Point') to the Wish Tower, composed principally of Upper Green Sandstone, but now obscured by the sea-wall and esplanade.

(3) The chalk cliffs, in most places much higher than the last mentioned, from the Wish Tower to Beachy Head.

In division (1) there is conclusive evidence of waste in recent times, though it is difficult to get any accurate information as to its extent and the rate of erosion. It is, however, quite evident that when the one-inch Ordnance Survey map was first published, in 1813, the Martello Towers numbered 69, 70, 71, 72 were some distance above high-water mark; they are now all destroyed, and only the ruins of two of them laid bare at low water, about half-way between high and low tide.

In division (2), the part between the Sea Houses and the Wish Tower, the evidence of waste is most conclusive. In a paper in the 'Phil. Trans.' for 1717, Dr. Tabor, of Lewes, minutely describes the position of the Roman pavement which had been recently found at Eastbourne. This was at that time '*distant from high-water mark a furlong*. In former times it might have been somewhat more, because from this point to the westward the sea is always gaining from the land.' The position of this pavement is approximately known. It was not more than a few yards from 'Splash Point,' the spot where stood the old house called the 'Round House,' which, being partly undermined by the sea, was pulled down in 1841. We have therefore the fact that between 1717 and 1841 nearly a furlong of land was destroyed by the encroachments of the sea in this particular spot.

Further evidence of this is supplied in the following quotation from 'Homely Herbert's Guide to Eastbourne,' 1857:—

'Immediately beneath where this house [the Round House] stood cattle were wont to feed in a delightful meadow. . . . It is supposed that within the last ten years no fewer than three acres of land have been washed away from hereabouts.'

Further to the westward the sea has also encroached much, as an ex-coastguardsman, who has been in Eastbourne for fifty-eight years, told me of a house which formerly stood east of the Wish Tower, the site of which is now covered with shingle, below high-water mark of highest tides. In front of this house he remembered a 'fair-sized garden,' and he had spoken with a man who remembered playing cricket in a field between this garden and the sea. The bluff on which the Wish Tower stands appears to have offered more resistance to the encroachments of the sea, as in the Ordnance Survey of 1813 it does not appear as such a prominent projection as it now is.

In the third division, from the Wish Tower westwards to Beachy Head, the chalk cliffs are higher, and there is less evidence of waste. Where the sea-wall now extends (as far as the disused chalk quarry at Holywell) there used, five or six years ago, to be sheer cliffs, their base touched by the highest tides, but they do not appear to have been wasting at all fast; while between Holywell and Beachy Head the cliff face is mostly crumbled and overgrown with vegetation, in some places right down to the shingle, showing that there, at all events, little appreciable erosion has taken place for some years.

At Beachy Head itself, the great height of the cliffs rising to 532 feet, and the immense mass which the sea has in consequence to wear down, prevents anything like rapid erosion, and, moreover, the base of these cliffs is, except for 200 or 300 yards at the actual point, composed of the hard Lower Chalk (without flints), which offers great resistance to the sea. It appears, indeed, that the upper part of the cliffs, under the influence of rain, frost, and salt spray, wastes more quickly than the lower from the attacks of the waves, as the latter usually protrudes, allowing the formation of the grassy slopes and green ledges which are the conspicuous beauty of Beachy Head. The occasional falls of the upper cliff slip over the lower strata, and form a talus of chalk ruin, sometimes jutting far enough into the sea to allow the shingle to collect to westward. This protects the cliff still more from the sea. Such a fall occurred about the year 1848, a little westward of the highest cliffs, and its effect in stopping the shingle was so great that the Commissioners of Pevensey Level took steps to hasten its destruction by blowing up the largest blocks of chalk with gunpowder. There

were formerly at Beachy Head three pinnacles of chalk projecting from the cliff top, and known as the 'Three Charleses.' These are mentioned as early as 1717 (in Dr. Tabor's paper before quoted), and though the last remaining fell into ruins in 1852, the bases of two of them still remain, showing how little of the cliff has perished in 150 years.

As to erosion before 1717, it seems impossible to obtain any accurate information. Sir Wm. Burrell (in the Burrell MSS. in the British Museum) mentions a survey of this neighbourhood, made by Sir Edward Burton in 1630, which he had consulted. But the agents of the present owner of Compton Place (the Duke of Devonshire) can give me no information about it, and it appears to be lost. This survey might have been of use if discoverable.

It is noteworthy that Dr. Tabor says that even at the beginning of the last century the sea was '*always gaining on the land*' at Eastbourne.

In Roman work at Pevensey Castle (*i.e.*, as early as the third or fourth century A.D.) unmistakable pieces of seashore rocks are built in belonging to the Upper Green Sand, or the Cretaceous stone immediately overlying it; some are rounded by water, and bear calcareous worm-casts, and some are perforated by *lithodomi*. This shows that as long ago as this date, the sea was washing the beds of the Upper Green Sand. It is, however, difficult to calculate the direction of these beds under the sea. There is no reef now existing hereabouts at any distance from the shore, the furthest being a reef of small rocks about a quarter of a mile from high-water mark, which is exposed at low tides. If this point were capable of being ascertained with any exactness it would afford a satisfactory chronological index.

With regard to the erosion of the whole of this part of the coast, from Beachy Head eastward to Langney Point, the consideration of most importance is the Langney shingle beds. For if we judge by the rate of waste of these beds since 1813, it is plain that they must once have extended some way eastward of their present limits. Additional evidence of this is found—

(*a*) In the Elizabethan survey, 1587, in which 'The Beache' is marked as continuing at least as far as Holywell, and is plainly distinguished from the tide-covered shingle.

(*b*) Camden speaks of 'the promontory called the Beach, from its gravelly beach,' as if the shingle reached actually to the headland in those days (Camden's 'Britannia,' ed. Gough, i. 189).

(*c*) In 1728 the Commissioners appointed to survey the coast of Great Britain say: 'The high ridge of beach runs on to a point of land beyond Bourn west, and there ends; which point, for that very reason, is called Beach Head, or Beachy Head' (quoted in 'Sussex Arch. Collections,' xi.).

The shelter afforded by Beachy Head, and the reef which runs out from it like a natural breakwater, if not the original cause of the formation of these shingle beds, may well have helped in their formation.

The sea-front at Eastbourne is now protected by a sea-wall and a system of wooden groynes, the spaces between which are soon filled by shingle washing from the west.

For some years past, in front of the Wish Tower, it has been the practice to allow rocks of the Upper Green Sandstone to be removed, and whole reefs, about half-way between high and low tide, have been thus removed. The authorities say that the removal of these rocks has greatly facilitated the washing up of the shingle into the groynes. But it is noticeable that where a large reef has been removed in the last few years, it has lately been found necessary to defend the sea-wall with a series of strong groynes set closely together.

D.—The Coast of East Kent.

By GEORGE DOWKER, F.G.S., Stourmouth, Wingham, Kent.

The district to which this Report refers is comprised within a line from Dover to Whitstable to the west, and the parts of Kent east of that line.

The shore line from Dover to Walmer on the south is composed of Chalk cliffs, containing flints, and ranging in height from two hundred feet to fifty; from Walmer to Deal, of clay, about twenty feet; from Deal to Pegwell Bay, of low marshes, raised towards the shore by the sand-hills, averaging about fifteen feet, and a sea-beach.

At Pegwell Bay are low cliffs of marly 'Thanet Beds,' which are succeeded by nearly flintless Chalk cliffs (in the bay), except the junction-bed with the Tertiaries, which contains numerous nodular and tabular flints. There are also large tabular Sandstone blocks, which occur in the Tertiary bed, and which are termed 'moorlogs' in the Ordnance maps. It is at this point that the present mouth of the Stour discharges its waters into the sea.

The remaining eastern coast-line from Pegwell to the North Foreland consists of Chalk headlands, about fifty feet in height, containing, for the most part, tabular and nodular flints.

The sea opposite the before-mentioned coast-line is called the 'Downs,' and at some distance from the shore are the dreaded Goodwin Sands, and numerous shoals that divide the tidal currents. The prevailing, or most rapid, current runs from south to north along this line of coast.

The northern shore-line from Whitstable to a little beyond Herne Bay is composed of London Clay cliffs, which vary from forty to seventy feet in height. From Beltinge (east of Herne Bay) to Reculvers the lower part of the cliff is composed of sand, with occasional Sandstone blocks, the latter more numerous towards Reculvers. From this point eastward, as far as Cliffend, at Birchington, the shore is a marsh below high-water line, protected by artificial embankments.

From Birchington to Foreness, near the North Foreland, the cliffs are of Chalk, nearly devoid of flint, ranging from thirty to fifty feet in height.

The sea opposite this northern shore consists of the mouth of the River Thames, which has numerous shoals, the largest and most remarkable of which is known as the 'Margate Sand,' being of a like character with the Goodwin Sands, to the south of the Isle of Thanet. The tidal current runs east and west; strongest from the east.

Sea-Beaches.

On the southern shore of this district are sea-beaches, for the most part underneath the cliffs, and piled up along shore, so as to form a natural barrier to the waves. These beaches have been travelling, and are still travelling, from the south towards the north. Artificial barriers across these beaches, at right angles to the shore, arrest this action, but the tendency of the sea-current is always to sweep round such obstructions, and the impinging force in such cases carries away the beach which had accumulated to leeward.

At Dover the construction of the Admiralty Pier has caused the beach to accumulate to the south-west, and, by the sweeping round of the tide, to remove the beach to the north of the town. A great change is perceptible in this respect since I have known the coast.

At St. Margaret's Bay the beach has diminished, and between here and Kingsdown a large quantity has been swept away during the last few years. Towards Walmer there has been a large accumulation, which is now rather stationary.

To the north of Deal and towards Sandown Castle the shore is being rapidly cut back. The beach alone here forms a natural barrier, and protects the low land behind it. Any cause tending to weaken or destroy this would cause the sea to inundate the Lydden Valley, some hundreds of acres in extent. The sand-hills beyond form a like natural protection.

In times past, the accumulations of sand blown on shore by the south-westerly winds have caused gain of land from the sea. At the same time, the prevailing currents have thrown back the mouth of the Stour more and more to the north, which has further gained from the sea a tract of land now protected by the sand hills.

At Pegwell Bay the sea has gained greatly on the land, washing away the cliff at a rapid rate, as my sketches taken here in 1849, 1868, and 1884 show.

From Ramsgate Harbour to the North Foreland, the shore below the cliff is covered with sand at high water mark, and there is little or no beach. Some falls of cliff have taken place, but the shore has not been materially cut back since I have known it.

From Walmer to the North Foreland there are very few groynes, and beach has been largely abstracted at different times artificially. Though some of the local authorities have prohibited this removal, it still goes on at places. Such removal must be prejudicial in exhausting the supply of material moved by the sea.

The *northern* shore of this area has comparatively little beach, and its removal should be strongly opposed. From the Foreness Point to the extreme end of the

Chalk cliff west of Margate, the fall of cliff has been very insignificant, and no flints, or very few, can be derived from this source.

Between this point and the Reculvers the marsh is protected by numerous groynes, kept up at great cost by the Commissioners of Sewers, which have been instrumental in keeping back the sea.

The London Clay cliffs along the remaining portion of this northern shore have suffered great denudation and destruction by the waves. There are some beaches below the cliff, derived, in part, from the gravel beds on the top of them.

The sea currents do not run so strong along this as on the southern shore of the area.

Coast-Changes.

There are evidences, both physical and historical, that relate to very great changes within this district. The Isle of Thanet, as its name implies, was once separated from the mainland by an arm of the sea, which has greatly been recovered from the ocean within the historical period.

I have not been able to discover any evidence of changes in elevation or depression within this area since the Roman occupation of England.

The estuary of the Wantsum, the river that separated the Isle of Thanet from the mainland, has been recovered from the sea, partly by human agencies, and in great measure by the silting up of the river, caused by the sea-currents diverting its mouth in a northerly direction, by the travelling of sea-beaches, and by accumulation of blown sand.

The Roman Rutupean ports and castra of Richborough and Reculvers were undoubtedly accessible to the Roman fleets.

Maps relating to the district, from the time of Queen Elizabeth, all show that the changes now taking place along the coast-line have all been acting in one direction, viz. a shifting of the strength of the tidal current from the south towards the north.

Between Sandwich and the Isle of Thanet an old sea-beach is situated, on one extremity of which was erected the ancient town of Stonar; the material of which it is composed shows it was derived from material brought from the north. The present sea-beaches from Dover to the North Foreland, on the other hand, are derived from material carried from the south.

There is no historical or other evidence to show that this beach has accumulated or been in process of formation during the period dating from the first century. But, rather, it would seem that it was not covered by the waves during the Roman occupation of Britain. I believe it was formed long anterior to that event.

If I am not mistaken, a similar alteration in the great tidal wave that sweeps round the coast of Britain can elsewhere be traced. And the removal of ancient land-barriers must have played an important part in these operations.

I am preparing a full Report upon this district, of which this must serve as a short abstract.

I have consulted the Reports made from time to time to the Admiralty Naval Department; Reports from the Board of Trade in reference to the beach at Deal; Mr. Redman's Essays on the Alluvial Formations and Local Changes on the South Coast of England; an Historical Report on Ramsgate Harbour by John Smeaton, 1791; various Reports on the south-eastern district prepared for your Committee; and all available archæological works relating to the subject, a list of which will accompany the full Report.

A tracing of the one-inch Ordnance Map accompanies this Report.

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1. Sidmouth.

By Peter Orlando Hutchinson, Old Chancel, Sidmouth, Devon.

1. Sidmouth and neighbourhood best, having resided mostly there since January 1825.

2. The cliffs reveal a fine section of the Trias, extending from Axmouth on the east (with a small interruption at Beer Head) to near Babbacombe on the west, a distance of 19 miles. **a.** The Red Marl at Sidmouth; but as the strata rise

towards Dartmoor, the cliffs towards Exmouth, Dawlish, &c., are composed of the Lower beds of Sand rock and coarse conglomerate. **b.** The height of High Peak, the second hill west of Sidmouth, by the Ordnance Survey, is marked as 513·9 feet high, reduced to mean tide, Liverpool. Peak Hill, next on the west from Sidmouth, is 439, and Salcombe Hill, east, 497 by the barometer. Though flat on the top, the high land rises inland, or northward, towards Blackdown, at the rate of about 50 feet in a mile.

3. From Beer Head to Sidmouth nearly east and west; farther west it curves round to the south-west and south towards Torbay.

4. In January and February either north wind and frost, or south and west with storms and rain. March, April, and part of May much cold north-east wind. June often showery, with westerly winds. July, August, and September, if not disturbed by thunder, steady north-west wind and fine weather. October equinoctial gales from south and west, with rain. November has generally a ten days' spell of frost. December often milder.

5. The south-west wind brings the highest waves, which come up Channel from the Atlantic. The south-west wind piles up shingle at Sidmouth, and the north-east winds clear it away. The shingle on this part of the coast seems to travel east or west according to the direction of the wind.

6. The tidal currents are intricate and varying, and change as the tide is rising or falling. The fishermen are not always clear on the subject. I am disposed to think that when the tide is rising, and the current running eastward in mid-channel, it strikes against Portland and turns back by a great eddy and runs past Sidmouth in the opposite direction. When the tide falls the currents are reversed, and every headland has its eddy.

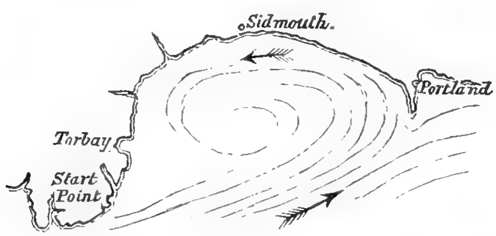


FIG. 2.—Eddy between Start Point and Portland—the tide rising.

7. (1) I have no trustworthy information on this point, and the local fishermen and sailors differ in their statements. It could easily be ascertained in calm weather. For the present I may observe that 12 to 14 feet is likely to be near the truth. The highest and lowest spring tides occur at the equinoxes. (2) This depends on the steepness or slope of the beach, which is steeper near high-water mark than low. On an average about 35 yards at Sidmouth.

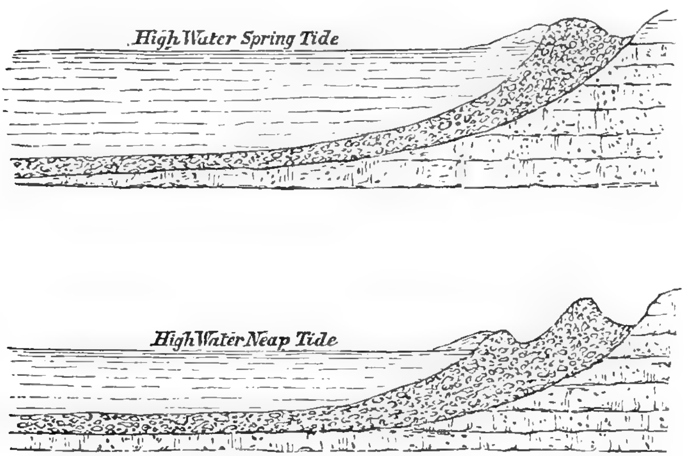
8. For miles on each side of Sidmouth it consists of chert and flint shingle, fed from the clay and flint bed capping the tops of the hills over the Greensand. At low water a flat sand is uncovered in some places. A low reef of rocks runs into the sea immediately on the west of Sidmouth, and is called the 'Chit Rocks.' They begin to uncover at half-tide down. No mud, but fine sand, called 'mud-sand.'

9. a. From the cliffs, or from the esplanade wall of Sidmouth (about 1,841 feet long), down to the beginning of the sand, the average width of the shingle is 35 yards. **b.** They cover the whole beach everywhere, the pebbles being from the size of peas to the size of the fist. **c.** The shingle travels east with a west wind, and west with an east wind. **d.** According to the size of the flints, some may be as large as a child's head. **e.** The shingle forms a curved slope (Figs. 3 and 4), but at high-water mark the waves throw it up into a ridge more or less high.

10. Curiously enough, the shingle seems to accumulate and to diminish by cycles—perhaps irregular, for I have no record of these changes. I remember a great accumulation of shingle, I think about 1847, and six or eight years after a considerable diminution. Again, about 1860, or soon after, it was heaped up so high as to be above the esplanade wall. It decreased till 1873, and by

January in that year it had become so cleared out, that from Belmont to the Chit Rocks, at the western end, the red rock was bare, and an extent of clay and river sand was exposed opposite Fort Cottage. Since then it has been returning.

11. This remarkable diminution had never been seen before, and caused great surprise. It was due to natural causes. The River Sid once had an outlet to the sea where Fort Cottage stands, as a bank behind the cottage shows, and which I have traced through the town inland. When the shingle was all cleared away, the surprise was increased by the appearance of a number of stumps of trees dotted about the beach between high and low water, and when the tide was in they were from 4 to 5 feet under water The stumps were worn short off, but they were evidently *in situ*, for on digging round some of them, which I did with others, the roots were found to radiate in the clay. They were of alder. I have several specimens. Also in the clay, probably washed down the river, five or six Mammoth teeth were found, most of which I secured. Three or four of the best I have given to the Exeter Museum.



Figs. 3 and 4.—Diagrammatic Sections through a Shingle-Beach.

12. In 1830 a number of groynes were made all along the beach in front of the town of Sidmouth, as an experiment, to see whether they would accumulate and retain the shingle. I saw many of the piles driven and much of the work done. **a.** They were carried out at right angles to the shore line, or line of the Parade, or Esplanade, as commonly styled. The Esplanade then was merely a walk on a bank of earth. The Esplanade wall, which is about 1,841 feet long, was not built till 1837. **b.** The length of the groynes, from their starting-point at the Esplanade, was about 30 yards, that is nearly to the commencement of the sand at low water. **c.** Judging only from recollection, I should say they were about 200 feet apart. **d.** Their height when built was about 5 feet at the inner end, and 3 or 4 feet at the farthest end. On the leeward side no shingle accumulated, but it became heaped up on the windward side. When the wind changed, say from west to east, the shingle was heaped up on the east, or new windward side, and cleared away from the west, or previous windward side, but new lee side; and when the wind was end on it was cleared away on both sides altogether. **e.** They were made of elm timber, to the best of my recollection. The piles were about 7 or 8 inches square, and perhaps 4 feet apart, and they were planked on both sides with stout elm boards some 2 inches thick. **f.** They disappointed the builders. They accumulated small portions of shingle in places, but wholly failed to retain it. When the gales of wind were strongest, and the waves were the highest and most violent in their attacks, and when the protection of a bank of shingle was wanted for the esplanade, and, indeed, for the sea-front of the town, then it got either washed away or got drawn back into deep water. After a few years' wear and tear the groynes began to show signs of dilapidation,

but as they were evidently useless for the purpose intended, they were left to their fate, and in a few years more they were either destroyed by the waves or utilised by the fishermen for firewood. They having failed, the esplanade wall was built in 1837.

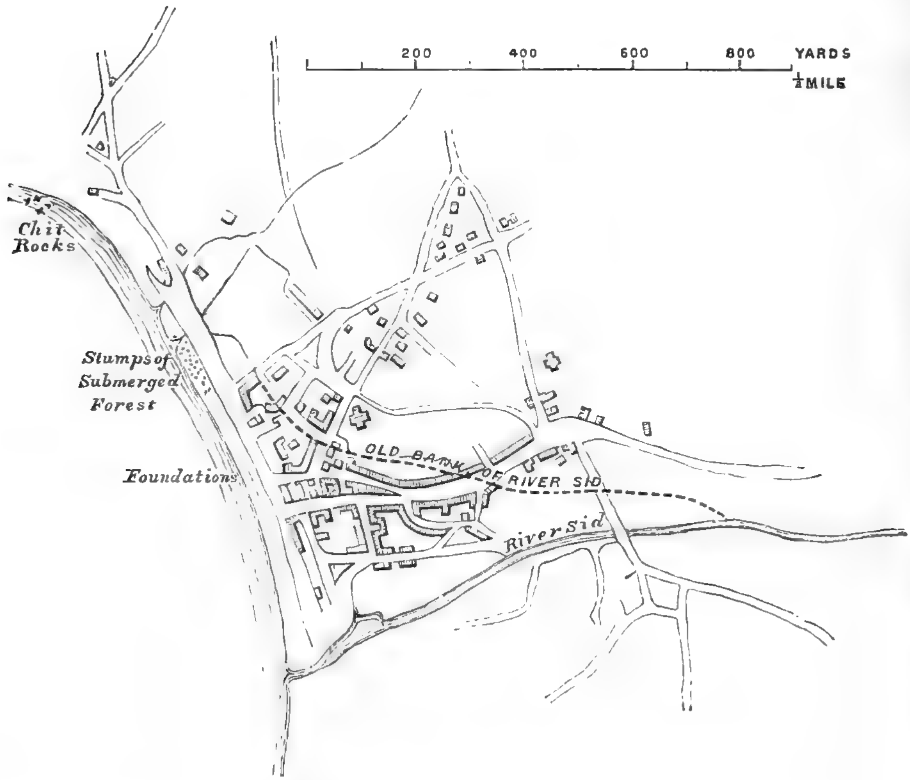


FIG. 5.—Plan of part of Sidmouth, showing the old river bank.

13. It has always been the custom at Sidmouth for the inhabitants to take sand and gravel from the beach. About 1870, speaking at a guess, the Board of Trade set up a new claim to the foreshore, and forbade such removal, but there was such a rebellion in the town that they dropped it. **a.** The material is taken from anywhere between high and low water mark, according as coarse or fine material is wanted. **b.** Gravel is used for gravel walks and roads, and many persons earn a living by fetching it when other business is slack. Sand of the coarser kind is used by the masons and others for mortar, cement, and various other purposes; but when this was forbidden, building was stopped, which not only affected the masons, but it concerned the carpenters, plumbers, painters, glaziers, &c., and hence the rebellion. **c.** All persons are free now to take any material they want from the foreshore, though the Board of Trade claims waifs and strays and certain large fish; but though this claim is new, it is not resisted. It was once enjoyed by the lords of the manor, for I have a lease granted by Henry VIII., in which it is mentioned; but the lords of the manor have neglected it. The small amount of material taken from the beach can have no effect whatever. The reef of rocks at the west end of the beach (the Chit Rocks) is too low to act as a natural breakwater, except at low tide.

14. a. and **b.** This is an interesting question and comprehends a great deal. I have been watching the wearing away of the cliffs from boyhood, and see great changes. The greatest loss is in the soft red marl from Axmouth to Sidmouth, and next in the sand-rock farther west to Exmouth, though hard patches of conglomerate occur in places. There is no regularity in erosion, for the softer

parts go fastest; and the waves attack the bases of the cliffs, and this brings down the upper portions. **c.** The rate of erosion in South Devon must be various. Perhaps I may say an inch a year for the last fifty years, which I remember; there are soft places in the cliffs that have gone twice or three times as much, and harder parts not half as much. **d.** I know of no old maps of sufficiently large scale or sufficient accuracy to determine changes of coast. Donn's (or Don's) map occurs to me, but it would be useless. **e.** The loss goes on everywhere, irrespective of shingle.

15. The questions under this head are virtually answered under **12** and **13**, as far as I am able. I will, however, here mention a circumstance which was told to me, at which I was rather surprised. When the esplanade wall was built in 1837, one of the coping stones towards the west end was trimmed after it was in position, and the chips fell several feet down, the shingle then being low. The south-west gales of wind during the winter after carried the shingle up to the top of the wall to the coping (6), but instead of burying the chips, my informant declared that they must have been lifted or forced up, for they were lying undisturbed on the top of shingle (6), and close to the coping stone. On inquiring how he could account for so strange a circumstance, he said he supposed that the pounding and beating of the heavy waves must have forced the shingle up bodily, and thus lifted the chips. I may add that I had not the opportunity of seeing the chips there myself.

16. No land is being gained from the sea along the coast of South-east Devon, but the contrary. The silting-up of shallows within the mouths of rivers, and the forming of mud banks, and eventually meadows, can scarcely come under this head. This latter process has given meadows within the mouths of the Sid at Sidmouth, the Otter at Budleigh Salterton, and the Axe at Axmouth. Silting-up is going on in the Exe, the Teign, &c., and eastward in Poole harbour, &c.

17. As the beach in South-east Devon, from Lyme to Exmouth, is composed of pebbles, and as high cliffs rise immediately from the beach nearly all the way, there is no blown sand there. There is, however, an expanse of sand a mile and a half wide at the mouth of the River Exe, occupying the width of the estuary, open to the sea and open at the back up the estuary. The seabeach is almost entirely of sand, and this expanse, called 'the Warren,' is composed of blown sand and estuarine accumulation, and all along the sea front there is a long ridge of sand dunes, between 20 and 30 feet high in some places. The waves in winter sometimes make breaches in this ridge, and the Mayor and Town Council of Exeter, who have rights here, have consulted engineers, fearing that the anchorage inside would be thrown open to the sea. But I think there is no danger. The features of the Warren may alter, and the sand will shift, but the reparations by blowing are always going on, so that I do not apprehend total or permanent destruction. Indications have been discovered of late years which go to show that the Exe once had an outlet under Mount Pleasant. Out of reach of the sea the sand is overgrown with bent grass, rushes, &c. And here is found the *Trichonema bulbicodium* (or *T. columnæ*), a small plant with a bulb about the size of a pea, belonging to France and the Mediterranean, supposed to have been thrown up by the sea. The Exmouth Warren is the only known habitat in Britain.

18. Many excellent papers on the Geology of South Devon have been written, though not exclusively devoted to the coast. There is not room to give full titles here. Besides the larger books, the following papers have come under my notice:—H. B. Woodward, Quart. Journ. Geol. Soc. 1876, p. 230; Geol. Mag. 1877, p. 447, &c. W. A. E. Ussher, Geol. Mag. 1875, p. 163; Quart. Journ. Geol. Soc. 1876, p. 367; Ibid. 1877, pp. 49, 449; Trans. Devonsh. Assoc. vol. x. p. 203 (On the Mouth of the River Exe); Ibid. vol. xi. p. 422; Ibid. vol. xii. p. 251; Aubrey Strahan, Esq., also of the Geological Survey, has a good knowledge of Sidmouth. Rev. W. Downes, of Kentisbear, Quart. Journ. Geol. Soc. 1882, p. 75, and many papers in Trans. Devonsh. Assoc. on the Blackdown Hills and Mid-Devon Geology. G. W. Ormerod, Teignmouth, Quart. Journ. Geol. Soc. 1867, p. 418; Ibid. 1869, p. 273; Ibid. 1875, p. 345 (Estuary of the Exe), &c. H. J. Johnstone Lavis, Ibid. 1876, p. 273, on Labyrinthodon. A. T. Metcalfe, Ibid. 1884, p. 257, being more about the Labyrinthodon. P. O. Hutchinson, Trans. Devonsh. Assoc. vol. xi. p. 383 (Fossil Plants in the Red Marl); Ibid. vol. vi. p. 232 (Submerged Forest).

19. There is one point on which I wish to make a remark, and that is, the universally prevailing opinion among the seafaring people on the south coast, that the sea is gaining on the land. This belief prevails at least from Portland to the Scilly Isles. Such a change can take place in two ways: one is, that the cliffs are receding before the waves, and the other is, that the land is going down. I have said above, at No. **14**, that the land is being worn away by the sea; and I may add that for twenty years past I have had a growing conviction that the land is going down. Not only does the sea appear higher and fuller than it used to do at high water, and points of land harder to go round at all times of the tide than when I was a boy, which signs, however, are not conclusive, but I have alluded to the submerged forest, and I may also allude to 'the foundations,' as some massive stone walls are called, supposed once to have been a habitable building, and within my memory generally uncovered, but not now. They are under the shingle, 30 feet outside the esplanade, and opposite Marlborough Place and Portland House. Like the stumps of trees, they are several feet under water at high tide. As to the rate of subsidence, I have thought that 10 inches in 100 years would be enough. In 800 years, or since the Norman Conquest, that would be 10×8 inches $= 80$ inches $= 6$ feet 8 inches. If the foundations and the trees were 6 feet 8 inches higher at the Conquest they would have been above the water, and the coast-line some distance farther out.

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2. Lyme Regis and Charmouth.

By RICHARD B. GRANTHAM, F.G.S., M.Inst.C.E., 22 Whitehall Place, London.

1. I have had occasion to examine the part of the coast of Dorsetshire lying between the town of Lyme Regis and the valley of the Char, near Charmouth.

2. Commencing from the west, along the cliff from Lyme Regis, the cliff consists of the Lower Lias Clay and Limestone, at first about 40 feet high, and at the highest part it rises to about 300 feet, and consists of blue Lias clay, capped with chert gravel, which is above the Lias, and overlies the Greensand. The cliff then descends to the River Char, and from the river eastwards the same formation appears on the cliffs, but they do not here exceed 50 to 70 feet in height. The land rises inland from the cliffs, but not very much. The shore as far as low water consists of thin beds of Lias rock, dipping slightly towards the east and seawards, and is the base of the cliffs. Water percolates from under the chert bed and Greensand, and finds its way down to the Lias beds, and appears on the face of the cliffs, and causes them to slip in large masses by degrees into the sea. This refers to the cliff where it is 300 feet and upwards in height.

3. The direction of the coast-line, after leaving the town of Lyme Regis, forms a bay bearing eastwards, and then curves back inland and continues east by south.

4. The prevailing wind is from the south-west, and is probably the cause of heavy seas.

5. There is no shingle.

6. They run up Channel towards the east and back to the west. The set of the tides between Beer Head and Portland Bill for eight miles east of the former is very various, and up to the latter is also extremely complicated and most difficult to describe. (See the 'Admiralty Tide-tables,' page 109.)

7. (1) The tides rise between Lyme Regis and Bridport $11\frac{1}{2}$ to $11\frac{1}{4}$. The neap tides rise in the same distance from $8\frac{1}{2}$ to $7\frac{3}{4}$. (2) The width varies from 200 to 230 yards at the mouth of the Char.

8. It consists of bare rock, as before described.

12. There are no groynes or shingle.

14. I could get no information as to the erosion or its position, and there are no local points to judge from.

16. Generally, along this coast there are no means of judging of any increase of land.

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3. Axmouth to Eype.

By HORACE B. WOODWARD, F.G.S., Geological Survey of England,
28 Jermyn Street, S.W.

1. Devonshire and Dorsetshire. Axmouth to Eype, west of Bridport.

2. The eastern cliffs, of which the highest point is Golden Gap (620 feet), are composed of Lias Clay and shale, capped by sand. Between Charmouth and Pinney the base of the cliffs is stone with clay above; the summit here is Black Ven (450 feet), where there is again a capping of sand. Between Pinney and Axmouth the sea-cliffs, of Red Marl, range up to about 60 feet; they are backed by high cliffs and undercliffs.

3. Axmouth to Charmouth, N.E. and S.W.; about E. 22° N. Charmouth to Eype, N.W. and S.E.; about W. 15° S.

4. South-west.

5. Lyme Regis—severe storm in 1824, after strong westerly winds; then gale arose from S.S.E.; wind veering to S. and S.W., drove the heaped-up waters directly on coast. Seatown, very changeable beach. Shingle mostly heaped up in fine weather; more sand after a north wind; a south wind pulls back the shingle. South-west wind, heaviest sea. South-east wind, highest tides. Lyme Regis, west of Cobb—south-west wind fills up beach; south wind draws off beach.

6. Flood tide from west, up Channel. Various local currents. Tide runs a good deal stronger up stream than down.

7. (1) 25 feet (maximum); 12 feet (Charmouth); 14 feet (Lyme). (2) 25 to 30 yards (Seatown); 300 yards (Charmouth), platforms of rock.

8. At high tide, sea dashes up against cliffs, east and west of Lyme Regis. Mostly fine shingle and sand, with patches of coarser shingle. East of Charmouth, a good deal of sand for a short distance, then all shingle to Golden Cap. Ledges of rock at low tide just west of Golden Cap. Black Ven, sand and ledges of stone and clay. Lyme Regis to Axmouth, here and there bays with shingle, otherwise tumbled material—large blocks of Lias and Greensand-chert, Chalk, &c., ledges of rock; nearer Axmouth, shingle with patches of sand at low tide, on platform of Red Marl.

9. a. and **b**. Beach of shingle, about 30 yards wide, at Seatown, *above* ordinary high-tide mark. Beach of shingle, about 22 yards wide, west of Golden Cap, *above* ordinary high-tide mark. **c.** *Generally* from east to west, being heaped up on *west* sides of slips. Some twenty or thirty years ago, after a great landslip at Golden Cap, the travelling of shingle was stopped for some time, and the sea dashed up against the Lias cliffs to the east, where usually there is a shingle beach that protects them. **d.** Seatown, mixed shingle, 2 to 5 or 6 inches, intermingled with fine shingle; 8×4 inches, many $3 \times 1\frac{1}{2}$ inches and less; chiefly flint and chert, some quartzites; a few slabs or flat pebbles of Lias; hardly ever any fine sand at Seatown. West of Golden Cap, 6×4 inches, many $2\frac{1}{2} \times 2$ inches, &c.; shingle rather smaller towards Charmouth—*westward*. **e.** Highest ridge at Seatown about 30 feet above low tide; lower ridge, 10 or 12 yards distant, 25 feet above low tide; spring tides do not usually come above this. West of Golden Cap, November 1884, highest ridge about 23 feet above low tide, extends 10 yards from cliff; second ridge about 15 feet above low tide, 12 yards from higher ridge, and about 30 yards from foreshore. East of Seatown the beach is almost entirely shingle as far as Down Cliff; it is 20 feet high in places.

10. Accumulates or diminishes according to wind and tides.

11. No.

12. A few in Lyme itself, to protect buildings inside bay formed by Cobb. **e.** Stone. **f.** To check the force of the breakers.

13. a. Stone taken from cliffs and ledges, east and west of Lyme. **b.** Lime, and chiefly for cement. About 10,000 tons sent to Hull for docks in one year. Amount varies according to demand. **c.** Yes. **d.** *Yes*; especially at base of Church Cliffs, east of Lyme. The church itself is now in considerable danger, the churchyard being at edge of cliffs. Shingle carted away at times from beach at Seatown for road-metal, but not from Charmouth.

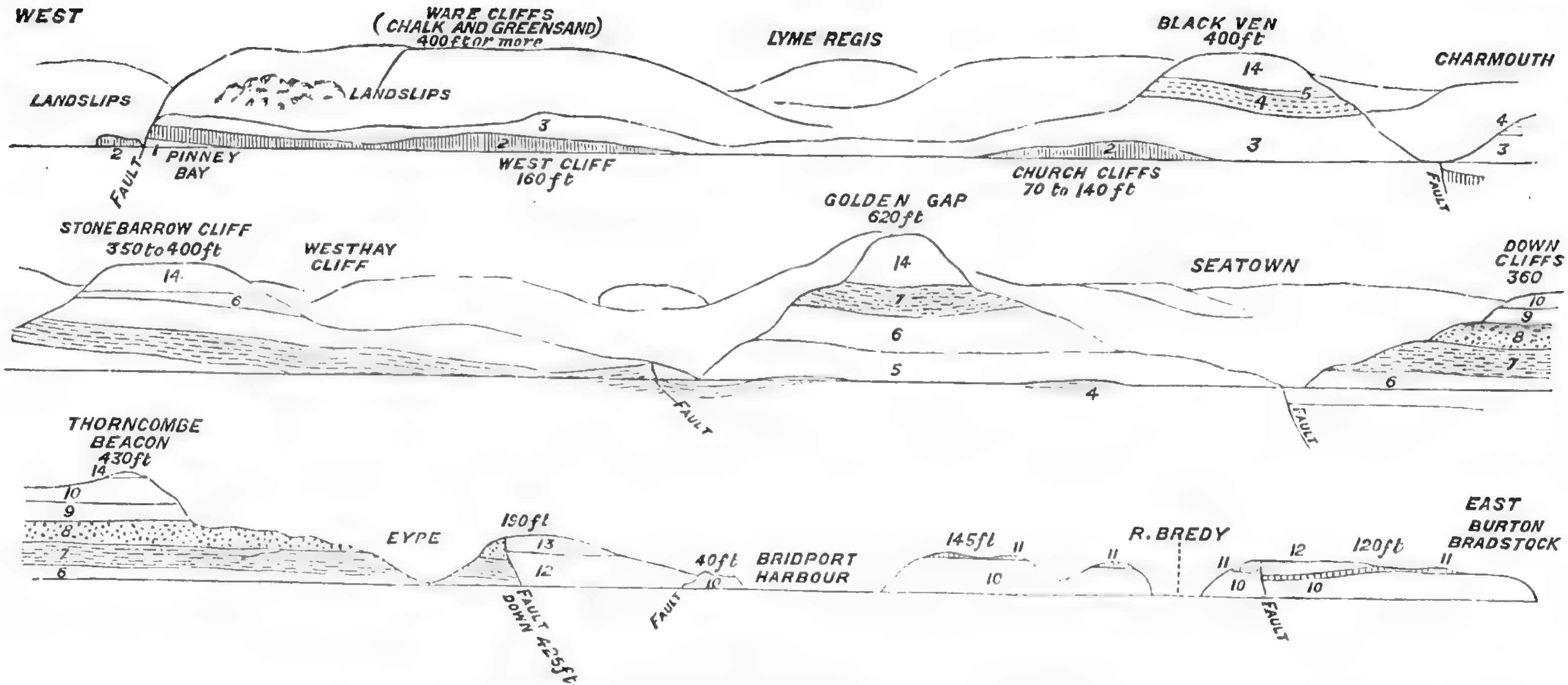

FIG. 6.—Sections of the Dorsetshire Cliffs. By H. B. Woodward.

Rhætic Beds	1. Limestone (White Lias).
Lower Lias	2. Limestone (Blue Lias).
	3. Clay.
	4. Marl (Belemnite Beds).
Middle Lias	5. Clay (Green Ammonite Beds).
	6. Clay { Clay. Three Tiers (stone).
	7. Sand and clay.
	8. Sand.
Upper Lias	9. Clay.
Inferior Oolite	10. Sand with indurated bands of sandy limestone.
	11. Limestone.
Fuller's Earth	12. Clay and marl.
Forest Marble	13. Limestone and clay.
Chert gravel, Upper Greensand and Gault	14. Sand and gravel.

Horizontal Scale about one and a half inch to one mile. Vertical Scale much exaggerated.
(These sections are published by permission of the Director-General of the Geological Survey.)

14. Cliffs, on the whole, are destroyed chiefly by slips, and the sea clears aways the *débris*. More especially just east and west of Lyme Regis—the lower Lias limestones, aided largely by the artificial removal of stone. Thorncombe Beacon : base of cliffs protected by large tumbled blocks of stone ; hence a slight headland is formed. Thorncombe Beacon was formerly much higher, according to men living in the district. Golden Cap protected by huge blocks of stone which have fallen from cliffs, also by ledges ; hence it forms a slight point or headland. Golden Cap, in the opinion of fishermen, has been lowered 30 or 40 feet during the past 30 or 40 years. The lowering of Golden Cap has been caused partly by reason of the hill-slope inclining inwards, and perhaps partly by streams carrying away sandy material at the junction of Greensand and Lias. West of Charmouth, a field of 5 acres about 150 years ago, now $1\frac{1}{2}$ acres. East of Charmouth, man aged about 75 (died about 10 years ago) knew when 'they went out milking where the beach now is.' Field reduced from 10 acres to 4 acres ; not gone much since. This field was evidently based on portions of an old slip, as, when removed, portions of old trees and shrubs were laid bare again. Oak-wood out of river-bed, ebonised and black as ink, sold for turning at the time. Seatown : road and four or five houses have gone on west side of river during last twenty years, owing to slips. One cottage gone by coast just east of river at Seatown, and man named Foss, innkeeper, æt. 84, says he dug portions of piles out of river, but the oldest inhabitant he remembers never heard of there being a harbour there, although the piles seemed to prove that such had been the case. Limekiln and road at Stonebarrow (about 50 yards) put back twice, and gone in last 60 years, and field of 11 acres (60 years ago) now 4 acres. The sea formerly (*i.e.*, 50 or 60 years ago) used to wash up against the cliffs of Stonebarrow ; now it only reaches them at extraordinary tides. Hence cliffs are not worn away so fast as formerly. If the cliffs were drained, there might be fewer slips, and hence the land would be protected. Lyme Regis, Church Cliffs : Lower Lias clay on limestone lost 90 feet in 30 years (1803–1833) (G. Roberts), partly by gradual mouldering and crumbling, without any great 'slide' or landslip, and partly owing to the removal of stone from base of cliffs and shore ; even the very *ledges of the shore were stripped off*, and this is the case now (H. B. W.). Roberts mentions that 'Table Rock' and the 'Horse Pond' are no more—ledges and hollows familiar to him in the early part of this century. He estimated the loss of the cliffs at 3 feet per annum in the soft strata, and 1 foot per annum in the harder rocks. There is still a soft ledge called Table Ledge under Black Ven (H. B. W.). Black Ven is subject to great slips. Roberts says (1834) three fields have gone during the past 100 years ; 90 years previously there was a lane from Lyme Regis to Charmouth, which has almost entirely disappeared. West of Lyme Regis, extensive landslips—Whitlands, 1765 and 1840 ; Bindon (or Bendon) and Dowlands, Christmas 1839.

16. No.

17. No.

18. Roberts, G.: 'The History and Antiquities of Lyme Regis and Charmouth.' Ed. 1, 1824 ; ed. 2, 1834.

19. I was informed by fishermen at Charmouth that a platform of rocks extended from Portland to Start Point, and this extended to about 10 miles distance from Charmouth ; beyond, the sea-bottom was mostly sand. On this platform there were accumulations of shingle (coarse and fine). On this subject, see Prestwich's paper on the Chesil Bank ('Proc. Inst. Civ. Eng.,' vol. xl. p. 61). I was also informed that at Seatown there was a fearful ground-sea on Friday, April 24, 1868, and that it raised the bank of sand and shingle 5 feet, and it so remained. The night before, there was an earthquake at St. Heliers.

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4. Bridport Harbour, &c.

By Horace B. Woodward.

1. Dorsetshire. Bridport Harbour or West Bay, Eype to Burton Bradstock.

2. Varied. Between Bridport Harbour and Burton Bradstock the cliffs are chiefly Sands with indurated bands ; to the west of Bridport Harbour and to the east of Burton Bradstock the cliffs are chiefly Clay and shale. Cliffs vary from 40 to 190 feet in height.

3. North-west and south-east. W. 30° N., and E. 30° S.
4. South-west.
5. a. South to south-west. **b.** South and south-east on east side of harbour; south-west on west side. **c.** South-west.
6. Flood-tide from west up Channel. There is an eddy-tide from the east on shore for two or three hours during flood-tide, and an eddy-tide on shore from the west during ebb-tide, two or three hours.
7. (1.) **a.** About 13 feet. **b.** From 3 to 5 feet. North-east winds reduce the height of the tide.
8. Fine shingle, with here and there patches of sand at low tide. From Bridport Harbour to Eype, the area is subject to frequent changes, being sometimes for the most part sand, at others for the most part fine shingle; this I have noticed during the month of August 1884. Below East Cliff, benches of bluish sandy limestone are exposed when the beach is uncovered; the top ledge would be about 16 feet above low-level spring-tide. Ledges or reefs of the same rock (indurated bands in the Inferior Oolite *Sands*) are generally exposed at low tide just to the west of Bridport Harbour.
9. a. About 20 yards at Eype. **c.** South-east. **d.** $\frac{1}{4}$ to $\frac{1}{2}$ inch diameter, near Bredy river mouth; occasional large blocks of stone, locally derived.
10 and **11.** Not to any appreciable extent.
12. No.
13. Fine shingle, removed from beach. **b.** Chiefly for ballast for vessels. Used also for ballast on new railway to Bridport Harbour, for platforms of stations, also for footpaths. (Sand is also procured occasionally for mortar, and pebbles are obtained *occasionally* for concrete, but only to a *very limited* extent.) **c.** Tract to east of River Brit belongs to General Pitt-Rivers, that to west belongs to the Earl of Ilchester. They are Lords of the Manors, and the ground is let out on lease to private individuals, who cart away the shingle, &c. The Harbour Commissioners have also certain rights to dig shingle. I am told by the Harbour-master, Mr. Martin Joseph Briggs, that 10,000 tons, which might be taken away in six months, would be replaced perhaps in one tide. He considers that no damage is done to the coast by the artificial removal of shingle.
14. c. East cliff, about 1 foot a year; sands and calcareous sandstone (Inferior Oolite Sands). West cliff, about 1 to 3 feet a year; chiefly clays and marls.
17. e. Blow over gardens and accumulate under walls at back of shingle.

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5. Weymouth.

By Bernard Henry Woodward, 80 Petherton Road, Highbury New Park, London, N.

1. Weymouth, north of town.
2. Shingle beach, bordering Alluvium, from about 3 furlongs north-east of St. John's Church, Weymouth, to the south of Jordan Hill. Oxford Clay cliffs at either end of shingle bank.
3. North-east and south-west.
4. South-west.
5. a, b, and **c.** South and south-east.
8. Chiefly shingle. Peaty alluvium exposed by mouth of stream south of Jordan Hill.
9. Tendency to travel south-eastward and inland; the road that borders the shingle beach having been 'put back' 60 feet during the last thirty years.
10. Diminishing.
11. Not allowed to be taken away now, although formerly the shingle was carted away.
12. Blocks of Portland rock are placed along shore to protect coast. Groynes were washed away in March 1883.
14. Oxford Clay cliffs below Jordan Hill are subject to most waste after a long dry season, when great cracks or fissures are made in the clay. Then autumnal rains, or winter rains and frost, act with great destructive power.

16. The shingle beach has probably dammed up an old tidal estuary, now the Alluvium of Lodmoor. And, further south, the chief part of Melcombe Regis, Weymouth, is built on marine sand and shingle which has contracted the mouth of the River Wey, and left a kind of broad, known as Radipole Lake or the Backwater. The water in this is now artificially retained at low tide by a weir.—[H. B. W.]

18. See R. Damon: 'Geology of Weymouth, &c.' Ed. 2, 1884.

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6. Christchurch to Poole.

By the Rev. G. H. West, Ascham School, Bournemouth.

1. Hants and Dorset—Christchurch to Poole.

2. Sandy. **a.** Sand and Clay cliffs. **b.** (1) ? 90 feet. (2) 70 to 80 ?. (3) About 15.

3. North-west to south-east.

4. South-west and west-south-west.

5. a. South-east is the only wind which can bring rollers in, as Studland Point shelters from the south-west. **b.** East wind. The shore is always shingly after east winds, which seem to check the 'travel' of the beach. **c.** Westerly winds, which coincide with the prevailing currents and flow of the tides.

6. There is a strong indraught (marked on Admiralty charts) along shore from Old Harry to Poole, but the main set of the tide is from Old Harry *straight* to Double Dykes (Hengistbury Head). There is also a strong current all along shore eastwards, especially at the second flow, which runs in a sort of fleet, cut off from the open sea by a sandbank. This is attributed, probably correctly, to the ebb from Poole Harbour, which, instead of running straight out to sea, flows out along shore through two openings called the 'Looes.' The general run of the tides here is—flow for about seven hours, then ebb for an hour, fall about nine inches; flow again for one hour and a half up to, or at *neap* tides higher than, at first. At spring tides the proper first flow and ebb are the highest, and the second flow is hardly perceptible. This second flow is generally attributed to the ebb from the Solent, but I do not believe this cause is sufficient. Besides, the tides appear to be very irregular all the way to Weymouth, and on the opposite side in the Baie de la Seine, high water lasts three hours (at Havre). Does not the old tidal-wave, which has been round Scotland, come back through the Straits of Dover and meet the up-Channel wave, being heaped up in the Baie de la Seine by the Cotentin, and reflected across Channel on to this coast?

7. (1) At spring tides the range is considerable. (2) Perhaps one hundred yards at *spring* tides, not above three or four at neap.

8. Sand generally, overlying Blue Clay, which in places comes to the surface between high water and low water.

9. b. The shingle varies extremely in amount. Generally it lies in small detached heaps, but during east winds sometimes forms a small neap full. It is not real shingle, but gravel which has come from the cliffs. **c.** It distinctly travels east. **d.** Chiefly small angular (Plateau) gravel, but there is a certain number of large grey pebbles, well rounded, which also come out of the cliffs. [Out of pebble-beds, or layers, in parts of the Bagshot beds.—W. W.][1]

10. Till 1867 the shore from this side of Double Dykes to the Head consisted of two large shingle fulls; in that year (owing to the removal of the ironstone in the Head, which formed a natural groyne reaching out to the Beerpan rocks) the shingle began to travel round the Head and form the sand-spit at Christchurch.

12. There are no groynes, except under High Cliff Castle, beyond Christchurch. There there are three or four, made about five or six years ago by Lady Waterford to check the wear at what was then the mouth of the river. Their object was rather to turn the river out than to protect the coast from the sea.

13. From 1847 to 1865 the ironstone was removed out of the Head, and from between high and low water, which formerly formed a half-tide reef. [Not done now. —W. W.] **b.** For a small private company, who exported it to Staffordshire. Private individuals (Mr. Holloway of Christchurch).

[1] The notes signed 'W. W.' are by Mr. W. Whitaker.

14. a. All along, but particularly at High Cliff Castle, Double Dykes, and Flag Head. (1) High Cliff.—Cliffs high, and rotten from landsprings. Waste very rapid, but checked now. Bute House, built 1760 (? about a quarter of a mile out at sea), was in 1830 so near edge it was pulled down, and present house built some considerable distance inland, now about 200 yards from edge. Half of the kitchen garden gone in 1875; in 1865 it was intact, and there was a path between it and sea. As this is the garden of the *old* house, if an estate map could be seen showing the old house, one would get a fair idea of the rate of waste, which was due only to the sea till 1867. (2) Double Dykes.—A little monument has been moved inland three times in about thirty years. N.B.—This is the point where the waste is most rapid this side of Christchurch, and where the main current hits the shore. (3) In 1850 there was a coastguard station at Flag Head and a field in front. The whole of this is now in the sea, and the 'Head' projects less than the rest of the cliff.

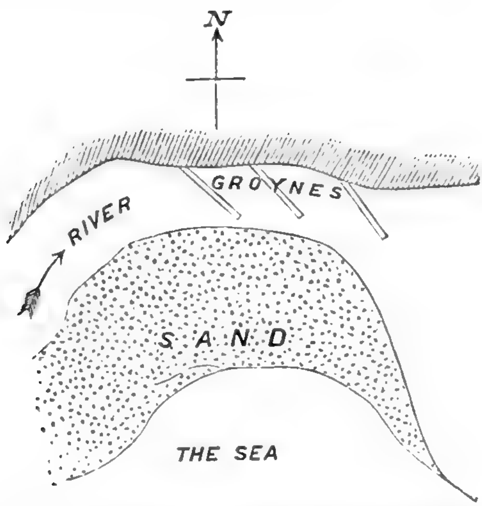

Fig. 7.—Sketch of Groynes, near Christchurch.

15. See **10.** **a.** No shingle is removed. **b.** There are no groynes but those at High Cliff.
16. None.
17. Yes, but they are small and only on the edge of the cliffs. Bent grass grows on them, but the fir woods are the chief check to their progress inland. [Refers probably to the blown sand along *top* of Bournemouth cliffs (see Geol. Map). —W. W.]
18. Papers by Redman and Coode, in the 'Proceedings of Inst. Civil Engineers.'

7. Sandown Bay.

By Lieut.-Colonel Garnier, R.E., Parkhurst, Isle of Wight.

1. The flat portion of Sandown Bay, between the cliffs at Shanklin and those at Yaverland.
2. a. Clay; blue slipper, covered with sand and shingle. Shanklin Cliffs, hard sand. Yaverland Cliffs, sand and blue slipper. (1) 120 feet. (2) 100 feet. (3) 0 feet; between Sandown and Yaverland.
3. North-east and south-west.
4. South-west.
5. a. South-west and south-east. **b.** North, because water is smooth in shore, and no undertow, which removes shingle as fast as it is deposited by rising tides. **c.** South-west.
6. Tide flows from south-west; ebbs in same direction.

7. (1) **a.** 10 feet. **b.** 8 feet. (2) **a.** 70 yards. **b.** 50 yards.

8. Clay; blue slipper with sand and shingle over.

9. Shingle. **a.** 20 yards mean; 50 yards greatest. **b.** Up to high-water mark. **c.** North-east. **d.** 5 inches by $3\frac{1}{2}$ inches. **e.** Continuous slope, except where affected by groynes, &c. With north wind there is a bank about 4 feet high formed at high-water mark, spring or neap tides.

10. Accumulating under Yaverland. A sea-wall was built thirty years ago from Sandown eastward, to prevent the sea washing away the coast road running along the flat portion of the coast, about half a mile in length. Before that there was an accumulation of shingle at the east end of Sandown which has since been swept more eastward.

11. It is stolen now and then from the above low portion of the coast.

12. **a.** Perpendicular to shore-line. **b.** From 60 to 250 feet. **c.** From 100 to 200 feet. **d.** (1) From 3 to 8 feet. (2) From 2 feet to 0, being sometimes covered with sand or shingle. **e.** Hitherto of wood; but last year (1883) two concrete groynes were built by Royal Engineers. **f.** The long groynes accumulate a greater mass of shingle, because they arrest the travelling of the shingle; the shorter groynes accumulate it chiefly at foot of sea wall. To preserve the latter from being exposed, and the blue slipper on which it is built from being washed away, numerous short groynes are necessary; but long groynes at intervals are required to arrest a large quantity of shingle.

13. Of late years all removal of shingle has been forbidden between tide-marks.

14. **a.** At Yaverland and Redcliff, about 100 feet in places in last thirty years, but a sea-wall has now been built at foot of cliff, opposite Yaverland. **b.** 100 feet to 150 feet; clay and sand mixed. **c.** No change observable for some years, probably because of the shingle now accumulating at foot of cliff. **d.** Originally the land between Brading Harbour and Sandown was covered by the sea. **e.** Probably (vide **c**).

15. The groynes east of Sandown to protect sea-wall do not appear to have prevented the accumulation of shingle at Yaverland.

16. No.

17. Yes, at St. Helens. **a.** Called 'Douvre.' **b.** 8 feet and 10 feet. **c.** At the mouth of the stream called the Yar, which runs into Brading Harbour. **d.** No. **e.** No. They are local drifts from the sands near Brading.

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8. Brading Harbour, &c.

By RICHARD B. GRANTHAM, F.G.S., M.Inst.C.E.

1. I know the coast commencing at the north point of Culver Cliff, and proceeding to Foreland. From the eroded beds of the Chalk, the coast is covered with stones lying on the red and green Clay of the Bembridge Clay. The coast has been very much eroded all round, to the Yar and Bembridge Point, where there is Sand and gravel, and a ledge of rock at Nodes Point, on the other side of the Yar. I and my son are consulting engineers to the Brading Harbour Company; we have executed the reclamation and harbour works on the Yar.

2. There are no tide-marks or means of noting the erosion, and there are no cliffs for this distance. At the entrance of the River Yar there are the remains of an old church, from which northwards the cliffs begin to rise gradually to about 100 feet. They consist of pale-greenish and yellowish Marls and Clays, hardening into Sandstones (with *Melania excavata*), dipping from the eastward, and rocks appearing on the shore; the whole in the Bembridge series. Along a great part of these cliffs the proprietor built a wall at the foot to protect them from slipping, but the water in them forced out the strata, and parts of the wall have fallen, and have not been repaired as occasion required. But the wall has generally stopped the erosion, and would have done so entirely if timely attention had been paid to it.

3. The direction of the coast-line from the Culver, above described, is north-east to Foreland; thence to the Yar, north-west; from the Yar to the Priory Estate due north, and thence to Nettlestone Point, north by west, to Sea View.

4. South-west, and consequently the cliff is protected from that wind; but the tide runs and erodes the cliff at its base for some distance. The edge of the land is low, and shore strewn with rocks washed out of the soil. The sea rises nearly up to the level of sand up to Sea View.

5. The above wind causes the highest waves and erodes the shore, which on the south of the island is much exposed to the heavy seas of the British Channel. There is little or no shingle on this coast, except in patches.

6. Is round the south point of the island, along the coast to Chine Head, and along the coast past the Culver Cliff and Foreland, and thence into Spithead, and thence up and down Portsmouth Harbour, and into and out of the Solent.

7. (1) **a.** 14 feet at Bembridge Point; **b.** 10 feet 6 inches. (2) There is no general width, as the shore for the most part is rocky or covered with rocks. In a few places there are sand and gravel beaches.

8. Bare rock, shingle, sand, and mud.

9. a. As previously stated, there is very little shingle, and only in patches. The breadth of these varies very much, they being principally scattered stones. **e.** The beach is extremely irregular in its surface.

10. There appears no accumulation or diminution, owing to the absence of shingle. The chief erosion is by stones being washed out. The rock appears in patches.

12. There are no groynes in this distance, except at Bembridge Quay, where one was erected about two years ago. Sand has accumulated on the seaside alongside the landing-place, and is prevented from filling the bed of the dock, or place for vessels to lie, 150 feet in length. **e.** It is built of stone, which was dredged out of the river Yar, in the harbour, to deepen the channel. **f.** It stops the sand from getting into the berth of the steamer at the landing-place, and is raising the beach with shingle, opposite the Royal Spithead Hotel.

13. None that I could hear of. **d.** Reefs have certainly protected—both half and full reefs.

14. c. There were no means of remarking the rate of erosion. **d.** I did not hear of any maps which would show the amount of erosion in this case.

16. The only increase I know of is the reclamation of Brading Harbour, consisting of 600 acres, by embanking it from the sea and forming quays for shipping. The embankment forms a roadway from St. Helens to Bembridge, and was constructed to reclaim the land for agricultural occupation. Quays were erected on both sides of the harbour below the seven sluices by which the water is discharged from the River Yar at low water. The ships bring coals for the southern and eastern sides of the island, in connection with the Isle of Wight Railway.

17. There are no dunes, and there is no blown sand on the coast. The only sand-hills are those on the north of the mouth of the River Yar; in front of them is a sand-beach, with gravel interspersed over it. The sandhills extend from the Yar for about half a mile northwards to the Old Church. The hills vary from 10 feet to 20 feet in height, and are covered with marram grass. There are sand-banks on both sides of the mouth of Brading Harbour and River Yar, and there is no shingle; the sand is not blown, but remains always the same height, and does not seem to extend.

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9. Bembridge, &c.

By Lieutenant NORRIS, R.E., Portsmouth.

1. Sea View, Isle of Wight, southwards to Bembridge and St. Helens, Isle of Wight. Much information was obtained from the chief boatswain of the Coastguard at Sea View.

2. Steep broken slopes, almost amounting to cliffs, intersected where streams run into the sea. **a.** Principally blue Marl—locally known as the 'blue slipper'—with beds of Limestone several feet in thickness, sloping about 5°. These strata are bent to a wavy section between the layers of blue Clay in places. Layers of red Sand and white Sand crop out occasionally. **b.** At Nettlestone Point, round Sea View: (1) 20 feet, (2) 7 feet, (3) 4 feet. From Horestone to Church Ruins: (1) 105 feet, (2) 50 feet, (3) 5 feet.

3. N.N.W. by N. to S.S.E. by S.

4. S.W. nine out of twelve months (off shore).

5. a. S.S E. to E.S.E. **b.** N.W. with a spring tide and swell deposits shingle in small quantities round Nettlestone Point, and round the fort at St. Helens. **c.** S.W. clears the shingle from Nettlestone Point, and replaces it with sand.

6. In shore at Nettlestone Point, tide runs $5\frac{1}{2}$ hours W. on flood at $3\frac{1}{2}$ knots; $6\frac{1}{2}$ hours E. on ebb at $2\frac{1}{2}$ knots. Off shore at Spithead, tide runs 5 hours W., 7 hours E.

7. (1) **a.** 18 feet. **b.** 11 feet. (2) At Nettlestone Point about 100 yards. Thence to Sea View Pier, about 150 yards. To end of sandbank outside Horestone Point rocks, about 250 yards. Horestone to Node's Point, about 200 yards. Node's Point to the Dovers, 300 yards to 500 yards. All at spring tides; half these distances at neap tides.

8. It consists of sand, limestone, or marl covered slightly with sand, gravel, or shingle, according to wind and tide; but between Sea View Pier and Horestone Point there are always 100 yards of clear sand. Opposite the Priory, and extending south of Node's Point, limestone beds appear on the level of the beach.

9. a. There is never any large quantity, except round St. Helens Fort. **b.** Accumulates near high-water mark, but varies with every tide. **c.** N.W. to S.E. **d.** Would pass through a 3-inch mesh. **e.** On Sand or mud shingle lies evenly and thinly; on rocky beach—Limestone beds—it fills the fissures.

10. Neither. In travelling S.E., a N.W. wind with a high spring tide to E. causes an eddy round Nettlestone Point, depositing shingle. It also is interrupted by St. Helens Fort. In S.E. gales, the backwash of the waves clears the coast of shingle.

11. Not diminishing (see **13.**)

12. Groynes are employed between Nettlestone Point and Sea View Pier, to protect the sand-beach from shingle, and to protect the sea-wall. Also north of Node's Point, 50 yards apart, rubble masonry at right angles to sea-wall, 5 feet thick at base, 5 feet high, and semicircular at top. **a.** Right angles. **b.** About 30 yards. **c.** About 30 yards. **d.** Present height, 3 to 4 feet above beach; present depth, wood about 5 to 7 feet, concrete 3 to 4 feet; apparent height varies with deposit left at each tide. **e.** A single row of halved 12-inch piles ($\frac{1}{2}$-round) with a longitudinal plank spiked on, or a straight wall of concrete 18 inches to 2 feet thick. **f.** Protect the sea-wall.

13. At Nettlestone Point only. **a.** Base of sea-wall at high-water mark. **b.** Building and roads. **c.** Private individuals. **d.** No; but the accumulated shingle at high-water mark protected the base of the sea-wall, now exposed.

14. a. From the Priory to Old Church ruins, principally round Node's Point. **b.** 50 to 105 feet at the top of inner slip. **c.** Average 7 feet in 12 months at present, but going locally about 20 feet at a time in a single slip, the contents of which, in S.E. gales, are carried off by the sea. The rate is increased by heavy rains and wet winters, as the slip is in the first place independent of the sea, which only removes the *débris*, which by its weight and the pressure of retained water forces out the sea-wall at its base. **e.** Yes, it is independent of the presence of shingle.

15. No. The course of the shingle lies outside the groynes, setting S.S.E. from Nettlestone Point.

16. None north of Brading Harbour, in which a company is reclaiming a large area by dredging and embankments.

17. Between Church Ruins and Ferry House on north side of entrance to Bembridge Harbour. **a.** At the Dovers (pronounced Duvvers). **b.** Mean 5 feet, some 15 feet, above high-water mark, ordinary spring tide. **c.** Occupying the north side of the entrance to Brading Harbour, opposite Bembridge, and the spit called St. Helens Sandbank. Brading Harbour forms the mouth of the River Yar. **d.** No. **e.** Yes; but as the ground is used for golf links, short grass has made a surface on the inside of the outer line of dunes, which prevents the heaps themselves from travelling. They form an embankment at high-water mark.

19. The serious loss of rich land at the top of the cliff is due primarily to the action of the Clay, or the 'blue slipper' (as is best seen at the undercliff of the Isle of Wight). This accumulates the rainfall, which presses against the sea-wall at the foot of the slopes. There is not more than one 3-inch weephole to 8 yards of wall, which is quite insufficient to relieve the pressure. The wall

is 7 feet high, 5 feet wide at beach, and 3 feet at top. Dovetail about 10 feet deep and of like section. North of Node's Point about 200 yards of this has been forced away, and is now being rebuilt as before in coursed rubble, stones being of no great size. The dovetail buttresses are too few, and placed near Node's Point, round which the wall has a semicircular trace, and has stood better than where it is straight, facing east. After rain, the fissures in the clay let the water through, and widen in the process, the mass supporting a breadth of 10 to 20 feet of the top surface gives way, carrying down trees, &c., and slips on to the second terrace of the slope, which in turn slips forward against the wall already supporting the water-pressure. This gives way generally at the beach level, just above the foundations. A S.E. gale then disintegrates the broken wall, and carries off the lowest portion of the slipped *débris*.

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10. Pagham.

By RICHARD B. GRANTHAM, F.G.S., M.Inst.C.E.

1. Pagham. I was engaged in 1875–77 by the office of Woods and Forests to report upon the effect upon the property of the Crown of the reclamation of the harbour from the sea by a Company, who had erected a bank and sluices for the purpose. The following information refers to the shingle-beach outside the harbour, on the sea-front.

2. The coast is generally low flat land, but at one part a large body of shingle has been for several years cast up by the south-west wind, and tides set round the point of Selsea Bill, where there is still water, causing a deposit of shingle. The shingle which has been brought there, is about half a mile wide and three miles long at low water. The harbour consists of 750 acres.

3. The direction of the coast-line is north-west up to Selsea Bill Point. Thence for 3 miles it runs north by east to the end of the shingle; in coming from the west the current passes Wittering and Earnly, and moves the shingle in a south-easterly direction.

4. South-west.

5. The south-west, which, as before stated, piles up the shingle, and moves it on along the coast towards Bognor.

6. After tides pass Selsea Bill, the current sets along the coast eastwards, and in the Channel the set is from west to east.

7. (1) Springs range up to $16\frac{1}{2}$ feet, and neaps to $12\frac{1}{2}$ feet. (2) About 880 yards.

8. Shingle opposite Pagham Harbour.

9. c. Opposite Pagham Harbour, east of north. **d.** They vary from 2 inches to 6 inches and 8 inches in diameter. **e.** The slope of the shingle is mostly uniform, but altered by heavy seas and strong currents. There are no tide-marks.

10. The top line of the shingle bank is neither raised nor diminished except in great storms, when the sea front is affected one way or another by storms or strong currents.

12. There are no groynes in any part of the coast within the limits of this report.

13. There is no material taken from the foreshore that I could discover or hear of.

14. The shingle bank entirely prevents any of the coast from being worn away by the sea for the whole length to which this report refers. **d.** I could find none, and it was not in the memory of any person when the bank did not exist.

16. Under this head it will be well to describe the harbour and works by which the land has been reclaimed. Upon my first visit, as stated in the beginning of this paper, to this harbour in 1875, for the Office of Woods and Forests, some large wooden sluices had been erected at the end of the stream on the land, from which the water, when the tide was out, was discharged into the channel of the former course, which I reported upon unfavourably on the next occasion, in 1877; and subsequently a new plan was adopted: a tunnel was made under the shingle bank to low water on the sea front, in which sluices were placed, and they have kept the land reclaimed safer. The water now passes directly seawards, at right angles with the coast.

18. I did not meet with any papers or maps except those of the Office of Woods and Forests, which were returned with an Act of Parliament. There was an arbitration held, which also condemned the wooden sluices which I referred to, and the tunnel and sluices were adopted.

19. This is but a small case, but is extremely important to those locally concerned; and shows also the cause of so large an accumulation in that part of the coast. I know of no other like it.

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11. Worthing to Lancing.

By RICHARD B. GRANTHAM, F.G.S., M.Inst.C.E., Inspector under the Land Commissioners.

1. Part of the south coast, between Worthing and Shops Dam, Lancing.

2. The coast consists of a wide shingle beach.

3. The coast-line curves inwards towards the north-east between the points above referred to.

4. The prevailing wind is from the south-west.

5. South-west.

6. The mean set of the tides is E. by N. along the line of coast, but in Mid Channel it is east and west.

7. The range of the tides is:—Springs, 14 feet; neaps, 10 feet.

9. a. The mean breadth is 40 feet. **c.** Eastwards. **d.** The maximum size of the pebbles is about 6 inches diameter. **e.** The front of the beach consists of two slopes. That from low water upwards is nearly flat, and towards the upper or crown rises steep from 2 to 1 and 3 to 1.

10. The shingle is accumulating, as will be described when referring to groynes.

11. It is not diminishing in height or breadth.

12. Groynes were commenced in 1873, and have to the present time been the means of arresting and accumulating shingle. They differ from the ordinary groynes, being of great length from the top of the shingle beach to beyond low water, probably 200 feet in length, and were placed 500 feet apart, forming an angle varying from 80 deg. to 63 deg., with the coast-line. They are fifteen in number, and are built of fir piles and planking, and supported by land ties. In places where the shore-line was not quite straight with the main line the beach was hollowed out, and intermediate groynes were placed which stopped the beach; these were of less length and height than the main groynes.

13. It is not removed artificially, as it is private property, from any part of the front line of the beach, but probably is taken for repair of roads at the back of the bank. **d.** There were no half-tide reefs formed anywhere in the distance above referred to as natural breakwaters.

14. The coast-line is not worn back by the sea, as the beach, as now protected by groynes, completely prevents such action, except just east of Worthing, where there was a shingle bank, and groynes were erected in a bend of the land, but the bank was swept away and the piles of the groynes were taken up, and near that spot the public road was cut through, and the sea flooded the land inside. The road led from Worthing to Lancing about three years since, but has not been reinstated. The piling and groynes at Worthing town are in a very bad state, and the shore requires quite a different kind of protection.

15. Entirely caused by the power of the sea near Worthing, by the abstraction of shingle.

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12. Lancing to Shoreham.

By RICHARD B. GRANTHAM, F.G.S., M.Inst.C.E.

1. I have become acquainted with the coast from near the Coastguard Station, which is on the beach opposite Shoreham, in Sussex, by being employed by the Land Commissioners to report on the erection of sea-groynes from there to Shops Dam, near Lancing, on the beach westwards, of which there are fifteen.

2. From the place described above to Lancing, as well as some distance westwards (for about $3\frac{1}{2}$ miles in all), the coast is formed of a shingle-beach of great width, but there are no cliffs.
3. It is north of east, curving towards the north as it approaches Brighton.
4. South-west.
5. From the west. It moves the beach eastwards, and has piled it up about 4 to 5 feet, and made it broader by accumulating it on the sea side. This refers to two-thirds of its length between the points stated above from the coastguard station to Shops Dam; and at the back of this length, an excavation was made by the proprietor of the adjoining land, from which a high bank was raised some years ago, adjoining the high road, to prevent the sea from overflowing; and a few years since he had these groynes erected, and I was appointed to inspect their construction. The front of Worthing has been thickly groyned.
7. (1) **a.** 14 feet 2 inches. **b.** 10 feet 1 inch. (2) About 90 yards.
8. Of shingle.
9. **c.** From west to east. **d.** Six inches diameter. **e.** The shingle forms a continuous slope from the low-water line to the top of the bank, but it is irregular, owing to the tide raising a bank along the face of the slopes, and washing out the shingle, causing flat places.
10. Since the groynes were constructed the shingle has accumulated. The sea has not flowed over the bank of shingle since the groynes were erected. The sixteen piles of groynes have cost nothing since they were erected in 1877–78.
11. The top of the bank has risen, and the shingle has increased in thickness on the sea-front.
12. **b.** About 275 feet, extending from low to high water. **c. d.** At their upper ends they are 500 feet apart, and are parallel to each other. At A on plan, three intermediate groynes were put in between groynes 8, 9, and 10, each 160 feet in length, and the shingle has completely covered them where the beach before was laid bare at that particular part. The groynes were built in 1877–78. They are built generally at an angle of 70° to 75° to the shore, or high-water line pointing south-east. **e.** Memel timber square piles driven into the beach, planked on the weather or west side, and stayed into the beach by land ties, fastened by piles at the ends. **f.** They are the means of stopping the beach and causing it to accumulate on the west side, raising it from 4 feet to 7 feet on the east side of the groynes, and thereby preventing the sea from eroding the coast.
13. No.
14. **b.** There are no cliffs except between Worthing and Lancing, where the land is higher than the public road. At one point near Worthing the road was washed away and some of the land at the back of it some years since. At the town of Worthing, the sea-front is protected by groynes which are very numerous, and sufficiently support the road; but this is beyond the district I personally know.
16. No; there is not any.
17. No; there are no 'dunes.'
18. I have inquired for such papers, but there are none. The only paper that has any account of these groynes and sea-shore is the 'Brighton Gazette' of February 26, 1885.

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13. Littlehampton to Brighton.

By W. E. C. NOURSE, F.R.C.S., Bouverie House, Mount Radford, Exeter.

1. The coast of Sussex from Littlehampton to Brighton, since 1832.
2. The land is bounded by a shingle-beach the whole distance.
5. Winds from the south-west, or thereabouts, have constantly made the waves *pile up* or *remove* shingle. *Piling up* has mostly been caused by moderate gales. *Removal or erosion* by storms. Besides which, the constant action of these winds on the waves has occasioned a constant travelling of shingle from west to east.
6. The sum of the ebb and flow is a set to the eastward, in which direction things always drift.

7. (2) Spring—at Worthing and Littlehampton said to be a mile, and appears quite that distance. Neap—at Worthing and Littlehampton, not a quarter the distance.

8. Sand, with occasional patches of small chalk rocks. The sand, off the east end of Worthing, rests on Blue Clay, found at a depth of less than 2 feet from the surface.

9. As already stated (**2** and **8**) the shingle is confined to the beach. The beach varies in form from time to time. After violent south-west storms it appears stripped away in many places, where not retained by groynes. After moderate gales it is piled up, not only by the sides of groynes, but also in longitudinal ridges at or near the top of the beach or half-way down, the shape, length, and duration of the ridges being constantly varied. At some seasons tons of seaweed cover the beach after a gale. Of the high shingle-beach existing in Queen Elizabeth's time, with a backwater to the landward of it, the only portion which remains is about Lower Lancing, and perhaps a little about Hove.

10. The shingle, which, as stated, is confined to the beach, has for some years past appeared to me slowly diminishing, but I do not know at what rate.

11. To artificial abstraction mainly, but not perhaps wholly.

12. Groynes are employed at various points, mostly at right angles to the shore. Groynes on this coast are of three sizes, according to their usual dimensions: small, which may be left out of the account; middling, of moderate height and length; and large, of greater height and length. Also, in some places, three or four are crowded together, elsewhere they are wider apart; again, considerable lengths of shore have no groynes at all. **e.** Most of them wood, one or two concrete. **f.** In all the years I have known the coast, the most erosion, the greatest encroachments of the sea, have been where shingle was deficient—that is, where there were no groynes, or insufficient ones. Erosions of limited size have also been generally observed to the eastward of *large* groynes, also to the eastward of spots where three or four groynes were crowded together; such erosions being noticed as hollows in the shore and more or less considerable notches in the land, while shingle was largely piled up on the west sides of the groynes. Erosions have always been noticed to be at a mimimum, or altogether arrested, where groynes of *moderate* height and length (according to their usual sizes), and in good repair, stood at (say) 30 to 100 yards apart, or at such distances as to maintain an *equal distribution of shingle* along the whole shore line, without piling it up at any particular part.

13. a. b. *Shingle* is taken from the beach about high-water mark. *Sand* is taken from various parts of the flat covered by the tide. The taking of these things has been usual as far back as I knew that coast, before 1830. *Shingle* has constantly been used to repair the roads within a mile or two of the shore; fine shingle has been taken for garden walks; large boulders to build with. Most of the walls within two miles of the sea have been built with boulders from the beach. *Sand* is mostly taken for building purposes. *The sands* at low water between Littlehampton and Lower Lancing used (1832 to 1842) to be noted for their extent, evenness, and firmness, so that they were favourite places for riding and driving. Races were then annually held on the sands both at Worthing and Littlehampton. Of late years (1850 to 1870) they have appeared to me not so dry and even as they used to be. At Brighton the sands are clearly at a lower level than formerly. The rounded chalk rock sticking up out of the sand eastward of the Chain Pier, near the first pair of towers from the land, in 1834 only showed a small portion of its rounded top. It is now visible 18 or 20 inches lower down, showing that the level of the sands is now so much lower than it was in 1834. **d.** Not to my knowledge.

14. The whole coast from Littlehampton to Lower Lancing has been in a constant state of erosion ever since 1832, some parts more than others. The worst part is at Kingston, near Rustington. Here the shore has been continually washed away for many years; at what rate I do not know. I have seen but little shingle here, and the sea washes up against the low clay margin of the flat land. I have always heard it reported that a large part of Kingston parish has been washed away, and that foundation-stones of the parish church can still be seen at extreme low-water mark. Dixon ('Geology of Sussex,' p. 34)

refers to the waste of land by the sea opposite the parishes of Rustington and Preston, mentions remains of trees on the shore, and speaks of Ruston Park, with large trees, standing [in 1704 [1]] on what is now the sea. He also (p. 35) mentions a tradition that [in 1704 [1]] the land at Tarring extended much further seaward. At Worthing like traditions prevail. I was told in 1832 that old men remembered the land being out as far as the grass-banks. Opposite College House School, Worthing, the sea in 1832 was washing away the beach, and laying bare the foundation of the playground wall. A moderate-sized groyne was put down, which made beach accumulate, and the encroachment stopped. I saw four similar groynes put down that same year opposite Mr. Elwes's large house; these also produced an even shingle beach which stopped encroachment. But just east of College House playground was an extra large groyne, with a great pile of shingle west of it and a large hollow eastward. Close to this was a coastguard house. About fourteen years after, I found that this house and the ground it stood on were entirely gone. Dixon (p. 37) says 70 feet of land were destroyed here in twelve months. Many years ago I saw the remains of the coast road, half washed away, that ran from Worthing past Heene towards Goring. The coast road from Worthing to Lower Lancing was then perfect and in regular use. I believe it is now dilapidated by the sea. The sea-front of Worthing, being cared for and protected, has never been changed within my recollection. Dixon (p. 37) says 'the sea formerly gained much on the shore.' At Littlehampton, the Baths, a building which stood on the beach in 1835, has been entirely destroyed.

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14. Newhaven and Seaford.

By A. E. CAREY, Resident Engineer, Newhaven Harbour Works, Sussex.

1. More especially the coast from Old Nore, Newhaven, Sussex, to Seaford Head.

2. The coast consists of two Chalk headlands, respectively 180 and 250 feet above sea-level, with an alluvial valley between, forming roughly the segment of circle to sketch. One mile from the eastern headland a low range of chalk hills about 60 feet high comes down to the sea front.

4. W. to S.S.W.

5. a. W.S.W. **b.** S. to S.S.E. **c.** N.W. to W.N.W.

6. The flood tide in the Channel striking Seaford Head causes a false or counter tide in Seaford Bay.

7. (1) **a.** 20 feet. **b.** 16 feet 6 inches. (2) **a.** About an average of 200 feet. **b.** About an average of 120 feet.

8. Shingle and sand, covering a partly artificial bank of clay and mud.

9. a. Depth varies so greatly that it is difficult to state with any accuracy. The greatest depth would be about 10 feet, mean depth perhaps 3 feet. **b.** Bank above mean high water varies little. Remainder of bank constantly varying. **c.** W. to E. **d.** Say 5 or 6 inches one way. **e.** Except above mean high water, the shingle forms generally a tolerably uniform continuous slope. After a succession of southerly winds, fulls are sometimes formed, but these are very variable.

10. The shingle is slowly diminishing, none now coming from the west side of the harbour.

11. To a small extent only from artificial abstraction.

12. a. About S.S.W. **b.** To low-water mark. **c.** About 150 yards. **d.** (1) About 8 feet out of ground. (2) About 4 feet, very variable. (3) About 1 foot, very variable. **e.** Timber piling planked. **f.** Their influence has been to arrest and maintain the existing banks of shingle. The whole of the system of groyning has been carried out by the Newhaven Harbour Co., who have recently constructed a sea wall about 20 feet in rear of the top of the foreshore bank, from the east pier to about $1\frac{3}{4}$ miles east of this. These combined works will render the foreshore secure, probably for many years.

13. a. Above high-water line principally. **b.** For the purposes of sea-walling, breakwater construction, &c. **c.** Under the Act of the Newhaven Harbour Co. **d.** No.

[1] These dates, 1704, are gained by calculation, not given by Dixon.

14. Yes. **a.** Especially in recent years opposite Blatchington Battery, which has for this reason been abandoned. **b.** Chalk cliffs about 40 or 50 feet high. **d.** Numerous maps exist of this strip of coast-line. A highway road between Blatchington Battery and the sea was washed away about twelve years ago. **e.** No; at Blatchington Battery the shingle is plentiful, and moves freely. A small groyne would probably arrest erosion at this point.
15. No; I think not.
16. Frequent floods, sometimes covering some hundreds of acres of land, occurred previous to the works named being carried out. On the west side of the harbour about seven acres of foreshore have been enclosed by a wall and reclaimed.
17. No dunes of sand exist here.
18. Numerous reports and maps of the sea-front exist, but these being out of print are difficult to obtain. Up to the time of the erection of a large groyne west of Newhaven Harbour in 1847–48 the movement of shingle was unchecked, and the loss at the east end of the bay was replaced by shingle travelling from the west. This groyne appears to have permanently checked the movement of the shingle, and erosion has taken place principally at the centre of the arc formed by Seaford Bay. The object of the present works is to retain what shingle remains, and to arrest its movement. A concrete sea-wall has been erected opposite the town of Seaford; and if this wall and that of the Harbour Co. were united (the distance being about 1,400 yards) Seaford Bay would be safe for many years. West of Newhaven Breakwater large deposits of shingle are accumulating.

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15. Beachy Head to Hastings.

By Colonel E. C. Sim, R.E., Royal Engineer Office, Brighton.

1. From Beachy Head to Hastings.
2. Mostly cliff, with the exception of Pevensey Bay, chalk, and sandstone. The greatest height is 512 feet—Beachy Head.
3. South-east.
4. South-west.
5. **a.** S.S.W. **b.** S.S.W. **c.** S.S.W.
6. To the eastward.
7. (1) **a.** 21 feet 9 inches. **b.** 15 feet. (2) **a.** 150 yards on an average. **b.** 120 yards on an average.
8. Shingle and sand.
9. **a.** 20 yards to 50 yards generally, but in Pevensey Bay the shingle is nearly a mile wide. **c.** South-east. **d.** 6 inches by 3 inches. **e.** Continuous slope.
10. Diminishing slowly.
11. Partly artificial.
12. **a.** South-west. **b.** From 80 feet to 250 feet. **c.** 100 yards at Eastbourne. **d.** (1) 12 feet to 15 feet. (2) 12 feet. (3) Full. They vary in length and distance apart at different places along the coast. **e.** Oak and beech. **f.** Prevent the scour of the sea, and to a certain extent retain the shingle.
13. **a.** Half-tide. **b.** Building and concrete work. **c.** Local builders. Corporation of Eastbourne, and Local Board at Bexhill. Newhaven Harbour Co. **d.** Slightly, near Beachy Head.
14. **a.** Generally. **b.** Sandstone and chalk. Height varies. **c.** It varies, but during the last twelve months about 10 feet at Bulverhythe, near Hastings. **d.** There are some old maps. **e.** No.
15. This cannot be stated positively. **a.** Probably to some small extent. **b.** Groynes appear to save one part of the foreshore to a certain extent at the expense of another. The breakwater at Newhaven Harbour appears to prevent the accumulation of shingle between it and Beachy Head.
16. No. The inroads of the sea are checked at Hastings, Bexhill, Eastbourne, Newhaven, Brighton, Worthing, &c., by sea walls, which there is a general tendency to extend.
17. No.
19. Two Memoranda by Colonel E. C. Sim, R.E., are forwarded herewith. [Printed on pp. 410, 412.]

16. St. Leonards and Hastings.

By Richard B. Grantham, F.G.S., M.Inst.C.E.

1. St. Leonards and Hastings, Sussex. I have examined the coast from the east end of Hastings to the west boundary of St. Leonards, as shown on the accompanying map on the Ordnance scale of 6 inches to a mile.

2. Commencing at Ecclesbourne Glen, the cliffs of the Wealden formation on both sides of the glen attain a great height, and from the east side continue westwards to the town of Hastings, generally about 200 feet high. The shore is covered by the rocks which have from time to time slipped from the cliff, and form beach varying from 20 to 70 feet wide. The erosion is caused by water behind the cracks and clefts in the face of the rocks forcing out the stone during frost, this being the chief cause. The height of the cliffs is from 80 to 200 feet above Ordnance datum. There is a large groyne of stone at the Sewage Works, at which the stone beach ceases and the shingle beach begins; 500 yards from there the buildings commence, and a quay wall at the Stade, opposite Market House, continues for a little more than two miles westward. This wall retains the roads in front of the two towns for that distance, and against it the shingle-beach rests. (See the 6-inch Ordnance Map.)

3. The direction of the coast-line is from west to east by north.

4. South-west.

5. a. South-west wind and south wind as the direct wind on to the coast of Hastings and St. Leonards. **c.** From the westward.

6. From west to east, which is shown by the accumulation on the west side of the groynes.

7. a. The range is 24 feet. **b.** The range is $17\frac{1}{2}$ feet.

8. Shingle with sand.

9. a. At Ecclesbourne the shingle is about 150 feet wide at high water, and at the Sewage Works about 200 feet, and continues pretty uniformly that width owing to the line of the retaining wall. **c.** From the westward. **d.** About 5 or 6 inches diameter. **e.** There is not a continuous slope, as it is in steps at the line where the last and strongest force of the tides left the shingle-bank.

10. I did not hear that there was any permanent accumulating or diminishing of the shingle except at the groynes, where it accumulates on the west sides of them, and against the face of the retaining wall, where in places as well as at the groynes the height was as much as 10 feet of accumulation.

11. I did not see or hear of any diminution at any part of this length, and I should suppose that as the Wealden rock forms the bed upon which the shingle rested, there would be neither diminution nor abstraction. For the whole of this distance nearly the rock appears, and slopes towards the sea and there meets the sand.

12. The groynes are very numerous, and in late years many more seem to have been placed all along this length except at the western end. [I have placed on the 6-inch Ordnance Map all the additional groynes, as will be seen by the lines in pink colour.] They have all been built of oak-timber piles and deal planks, and are tied into the beach by trees of oak. They arrest the shingle, which accumulates on the west sides; in some places at their upper ends the beach is as much as from 6 feet to 10 feet higher than on the east sides. They are generally placed at right angles to the front wall, and in some cases are upwards of 200 feet long, but generally 120 to 150 feet long. The distances apart vary very much, but the tops of them are level with one another in nearly all cases. The influence that they have exerted is to protect the wall or any building against which they abut.

13. I could not discover or learn from any person that any materials were removed artificially or otherwise, but I believe that a strict watch is kept in order to prevent any removal. **d.** I heard of none and saw none.

14. No. **b.** The cliffs, except east of the town, do not wear away, as they are protected by houses or walls.

16. There has been no increase of land by the accumulation of shingle.

17. There are no 'dunes' in this district.

18. I tried to get maps, sketches, or pictures, but I could not find any of value for the purposes of this inquiry.

17. Dover.

By E. R. N. Druce, M.Inst.C.E., Engineer to the Government Pier, Dover.

1. The part in the neighbourhood of Dover (South-East coast).
2. Cliffs. **a.** Chalk. **b.** Shakespeare Cliff is, I believe, between 350 and 400 feet; average is 200 feet.
3. East and west.
4. South-west.
5. **a.** **b.** **c.** South-west.
6. Up and down Channel, east and west.
7. (1) **a.** Nineteen feet. **b.** Eight feet six inches.
8. Shingle and sand generally, but there is a boundary jetty at the east end of the Dover Bay which stops the shingle. To the eastward of this jetty the chalk rock is bare.
9. **a.** **b.** In Dover Bay the general width is 250 feet, about half of which is *above* and half *below* high-water mark. **c.** Its tendency to travel is *with* the prevailing wind, that governing the waves. **d.** About 2 inches maximum dimension with a tendency to decrease.
10. Diminishing all along the coast from Dungeness to Deal, except at such intermediate points where artificial means have been taken to arrest its progress.
11. Only partly. There is a loss by friction on travelling, but the supply from the westward no longer continues.
12. **a.** Generally at right angles or perpendicular to the shore-line. **b.** Various. There is no system, whether with reference to structure or height or length; some are 150 feet long. **c.** Sixty to seventy yards, where there are any. To the west of Dover the greater part has disappeared altogether. **d.** (2) The top line of the latest built, which are at the east end of the Bay, runs from five feet above high water to about two feet above low water. In Dover Bay the upper portion of the groynes at this date are buried in the shingle, and there is no variation in the levels of the shingle on the east and west sides. They seem to have been constructed with reference to their own security, and have no apparent effect on the shingle. **e.** The best are made of double railway irons with three or four-inch planking. **f.** Both to the west and east of Dover Harbour there are large boundary groynes of stone which retain to some extent the shingle within the extreme limits of the authority which has the control of them. There are, then, the various intermediate timber and railway iron groynes which more or less, according to their height and length, arrest the movement of the shingle.
13. **a.** Above high water. **c.** Principally local authorities. **d.** There are no tidal reefs.
14. Yes. **a.** Both to the east and west of Dover. At Shakespeare's Cliff to the west, where the cliff is at the maximum height (between 350 and 400 feet). The cliffs are also falling to the eastward of Dover, where they are from 200 to 250 feet in height. This is the result of their being undermined by the sea. **c.** It is at no particular rate, but falls of cliff at the points above named have taken place at intervals for some years past from the cause above stated, and since they have lost the protection of the shingle at their base. **d.** I think none. **e.** Yes.
15. It is due partly to the supply of shingle having been arrested at Folkestone, which is to windward of Dover. At the same time the supply to Folkestone has of late years greatly decreased in common with all the shore to the east of Dungeness Point. See Sir J. Coode, Report referred to in **18**.
16. No.
17. No.
18. Dover Pier.—Return to Order of the House of Commons, March 13, 1873, for copy of 'Correspondence relative to the Causes of the Wasting of the Shore to the Eastward of the Government Pier at Dover.' This contains Sir J. Coode's Report on the subject, dated July 3, 1873.
19. There is a large increase in the area of shingle to the westward of Dungeness. All the shore, speaking generally, to the eastward of Dungeness as far as Deal is now suffering from the supply being stopped. The groynes above referred

to may prevent to some extent the waste which results from friction, but unless the authority in each district provides boundary jetties with intermediate groynes, to 'fix,' as far as possible, the shingle, the whole of this part of the coast will, in my opinion, suffer from the want of the natural protection which the shingle has hitherto supplied. The cliffs are now being undermined in places, and must eventually fall.

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18. Deal.

By Major A. C. HEPPER, R.E., Royal Engineer Office, Dover.

1. None, but I have made inquiries relative to War Department property at and near Deal, where the coast-line is, and has been, undergoing change.
2. Shingly beach at Walmer, Deal, and Sandown Castles, and No. 2 Battery; cliffs at Pegwell Bay Battery, Ramsgate, and Broadstairs. **a.** Chalk and flint. **b.** About 70 feet; 65 feet; 60 feet.
3. North and south.
4. South-west.
5. **a.** North. **b.** South-west. **c.** South-west.
6. North-north-east and south-south-west.
7. (1) **a.** From 18 to 20 feet, according to wind. **b.** From 12 to 15 feet, according to wind. (2) About 40 yards at Walmer, increasing to about 280 yards at No. 2 Battery.
8. Shingle, sand, and patches of rock.
9. **a.** Greatest about 450 feet; mean about 200 feet. **b.** Heaped up towards high-water mark; sand below half-tide. **c.** North. **d.** Size of an egg, but occasionally much larger. **e.** No, it is heaped up and changes with every gale.
10. At Walmer Castle accumulating; at Deal Castle variable, now accumulating; at Sandown Castle diminishing; at No. 2 Battery accumulating.

Place	From	To	Increase. Feet	Decrease. Feet
Walmer Castle	1741	1841	308	—
" "	1841	1859	34	—
" "	1859	1872	33	—
" "	1872	1884	10	—
Deal Castle	1741	1859	85	—
" "	1859	1872	—	40
" "	1872	1884	35	—
Sandown Castle	1741	1859	—	145
" "	1859	1872	—	50
" "	1872	1884	—	5
No. 2 Battery	1859	1884	140	—

11. No.
12. Groynes not employed.
13. Not so removed.
14. Yes, the cliffs are liable to landslips from action of sea at base. **a.** Pegwell Bay, Ramsgate, and Broadstairs. **b.** Chalk and flints; height about 65 feet. **c.** Not known. At Broadstairs one landslip, causing a loss of 30 feet, has occurred since 1870. At Ramsgate a slip in 1875 set back edge of cliff about 5 feet. **d.** Ordnance and other maps in Royal Engineers' Office and Report of Committee on Coast Defences (confidential). **e.** No.
15. No.
16. No.
17. Yes, between Deal and Pegwell Bay. **a.** Sandhills. **b.** Mean about 10 feet; greatest about 15 feet. **c.** They are situated in rear of shingly beach of Deal Roads, and bordering the mouth of the River Stour. **d.** No. **e.** Not blown, being old and covered with vegetation.
18. See **14**, **d.**

19. Sheerness.

By Colonel LE MESURIER, R.E., Sheerness.

1. Sheerness, Isle of Sheppey.
2. Foreshore, about half-tide, of London Clay. Formerly salt marsh, now protected by clay, sea-wall paved with Kentish rubble rag, grouted with Portland cement, shingle at foot of wall. **a.** Cliffs of clay and loam from Warden Point to Scrapsgate Minster **b.** (1) 150 feet; (2) 100 feet; (3) 15 feet.
3. East and west.
4. East and north-east.
5. a. East. **b.** West and north-west. **c.** East.
6. From the north-east.
7. (1) **a.** 17·6; **b.** 12·6. (2) Opposite Sheerness, about 1,320 yards.
8. Mud and shingle.
9. a. About 70 feet and 120 feet. **b.** Between high and half-tide marks. **c.** East to west. **d.** About 7″ × 4″ = 5 lbs. **e.** One continued slope.
10. In some places one tide might take it all away if not retained by groynes. In others it is accumulating; owing to the groynes it is generally accumulating.
11. Diminution is due partly to artificial abstraction, partly to want of groynes.
12. a. Generally in a north-east direction. The west-direction groynes now run out at right angles to the sea-wall for about 50 feet, and thence towards the north-east. **b.** From 50 to 150 feet. The principal groynes are being lengthened to 200 feet; at salient portions of the coast the minimum distance is necessary, at re-entering portions the maximum is sufficient. **c.** From 50 to 300 feet. **d.** 1 foot 10 inches above the surface, and 1 foot 10 inches below—i.e. of four 11-inch planks. As the shingle accumulates to windward, planks are fixed one at a time. If the groynes are put near enough there need not be a greater difference of level than 2 feet, except on extraordinary occasions. Sometimes there is scarcely any difference. **e.** Oak-framed uprights, 11′ × 11″, sills bedded in concrete 8 feet apart, 3-inch fir planks bolted to these uprights. **f.** They catch and retain the shingle, forming an artificial beach or half-tide reefs, and thus protect the toe or foot of the sea-wall.
13. a. Near mean high-water mark. **b.** For concrete work and building requirements, footpaths, &c., by local builders and the War Department and Admiralty contractors. **c.** The Lord of the Manor of Marine Town, sea frontage, and of the land adjoining the boundary of Sheerness and Minster, east of the Co-operative Coal Pier. **d.** In some parts of the coast such half-tide reefs exist, and do so act. In other parts they have been removed, but whether by the increased force of the tide, owing to the removal of the cliff to the eastward, or by artificial abstraction appears a question.
14. Yes. **a.** The entire length of the island from Sheppey-Landsend, Warden Point, to Garrison Point Fort. **b.** Cliffs of loam and clay about 100 feet high from Warden Point to near Scrapsgate Minster, thence to Garrison Point. Clay and mud foreshore with more or less beach or shingle. **c.** No record in Royal Engineers' office. The parish of Warden has lost upwards of 220 acres within 220 years. **d.** It is understood that the Mayor or Corporation of Queenborough possesses a map of Sheppey dating from the reign of Elizabeth. **e.** Nearly so; the loss is greatest at the north-east part of the island, called Warden Point. Here the coast is quite bare of shingle.
15. No.
16. There is no increase whatever now. The area covered by shingle is becoming less every year. **a.** Nil. **b.** Much of the lowlands or marshes of Sheppey have been regained from the sea within the past 300 years.
17. No.
18. The earliest map of the coast-line adjoining Sheerness that we have in the Royal Engineers' office goes back only 150 years—it does not extend beyond a mile to the east of Garrison Point.

20. Chatham and Sheerness.

By J. CHISHOLM GOODEN, 33 Tavistock Square, London.

1. Have known the estuary of the Medway, between Chatham and Sheerness, and reported on it to the hydrographer of the Admiralty, Sir F. Beaufort, who ordered its resurvey by Captain Bullock, R.N. This resurvey confirmed my conclusion that a frightful waste of land existed there by erosion.

2. Alluvial soil.

7. (1) Chatham Dock. In 1840, Captain Bullock, R.N. **a.** 17 feet 3 inches. **b.** 10 feet 6 inches. In 1868, resurvey by Commander Calver. **a.** 18 feet. **b.** 14 feet 6 inches.

14. Medway estuary. Captain Bullock, R.N., reported to me May 28, 1880: **a.** Waste at Ockam Ness, 157 feet in fourteen years. Personally stated to me that the waste at Sharpness on the opposite bank of this river was 11 feet per annum during the same interval. Bishop's Marsh, 5 or 6 feet on all sides, and therefore the double. Hoo Marshes and St. Mary's Marsh, 3 or 4 feet. Upper Marshes, 2 or 3 feet. All this waste must have been intensified and increased greatly by the greater action of the waves derivable from greater water surface and the greater power of wind on the water. **d.** There are no data present to illustrate this; Admiralty appear to have stereotyped the configuration of the land here. There is an early map in the British Museum, *circa* Queen Elizabeth. There is Steele's map of 1802. Some of the soundings there were repeated by people I questioned, before Captain Bullock's second survey. **e.** There was scarcely any hard ground in my time, except in Upnor Reach. Some was said to be in existence in Wollopstone ooze, but I failed to find it by experiment of a disagreeable character. The creeks and inlets show remarkable shoalings.

15. Honestly think and say No, unless tidal oozes are land.

18. There was a correspondence on Rochester Bridge and the River Medway in 1812, and a blue book ensued from it, with observations by Rennie, C.E. The report of the City Corporation Commission, 1853, deals with evidence from Captain Bullock, R.N. I have written in the 'Times,' 'Athenæum,' and 'Household Words' on this matter.

19. My belief is, from the excessive waste of land, long continued, and necessarily increased, that the oozes must be rising; and there was evidence, after Captain Bullock's second report, that at Bishop's Spit the ooze had spread at the foot. My impression is that here, by natural action, we are slowly realising what the artificial works of the abbots of St. Augustine's and the Great Church of Canterbury did towards the loss of Sandwich Haven. They 'inned' the oozes and converted them to useful purposes; we do not; but we have considerable national properties at Chatham and Sheerness. We have the most imperfect data as to oozes; the charts do not give the depths thereon.

Chronological List of Works on the Coast-Changes and Shore-Deposits of England and Wales.

By W. WHITAKER, B.A., F.G.S., Assoc.Inst.C.E.

Having made many lists of geological works on various parts of England, from a topographical point of view, it occurred to me, some time ago, that there might be some advantage in having such lists arranged by subjects. The following is a first attempt in this line, and it may perhaps be of service to the Committee, and to those local observers working with it.

It is confined to the subject-matter of the Committee's inquiry, namely, changes within the historic period; and therefore, whilst it includes the titles of papers that refer to these recent changes and to the beds which are formed along our shores, including the so-called Sub-

merged Forests that generally occur beneath the beach where a stream flows into the sea, it does not include papers that merely give an account of cliff-sections or of raised beaches.

This list does not pretend to perfection, and notice of omissions will be thankfully received, so that any such may be included in a supplementary list, in some future Report. Of course such sheets of the Geological Survey Map as show sea-coast, give information on shore-deposits, but it hardly seems needful to mention each separately.

I have to thank Mr. Topley for many of the 431 entries now made.

1675.

Anon. The Improvement of Cornwall by Sea Sand. (Notes character, &c., of sand.) *Phil. Trans.* vol. x. no. 113, p. 293.

1701.

Wallis, Dr. J. A Letter Relating to that Isthmus, or Neck of Land, which is supposed to have joyned England and France in former Times, where now is the Passage between Dover and Calais. *Phil. Trans.* vol. xxii. no. 275, p. 967.

1717.

Musgrave, Dr. W. De Britannia quondam pæne Insula Dissertatio. *Phil. Trans.* vol. xxx. no. 352, pp. 589

1751.

Desmarets, N. L'Ancienne Jonction de l'Angleterre à la France; ou le Détroit de Calais, sa formation par la rupture de l'isthme, sa topographie et sa constitution géologique. [Invasions of Sea.] Reprinted in 1875. 12mo. *Paris.*

1754.

Borlase, Rev. W. An Account of the great Alterations which the Islands of Sylley have undergone since the Time of the Ancients, who mention them, as to their Number, Extent, and Position. *Phil. Trans.* vol. xlviii. p. 55.

1756.

Borlase, Rev. W. Observations on the Ancient and Present State of the Islands of Scilly. 4to. *Oxon.* 1756.

1758.

Borlase, Rev. W. An Account of some Trees discovered underground on the Shore at Mount's-Bay, in Cornwall. *Phil. Trans.* vol. l. p. 51.

1777.

Jacob, E. Plantæ Favershamienses. with an Appendix on the Fossils of Sheppey. (Waste of Cliffs, p. 130.) 8vo. *Lond.*

1779.

Charlton, L. The History of Whitby, &c. (Waste of Coast.) 4to. *York.*

1786.

Lyon, Rev. J., and E. King. Letters giving an account of a Subsidence of the Ground near Folkstone, on the coast of Kent. *Phil. Trans.* vol. lxxvi. p. 220.

1790.

Gillingwater, E. An Historical Account of the Ancient Town of Lowestoft, in the County of Suffolk, etc. [Changes of the Coast, etc.] 4to. *Lond.*

Locke, R. On the Improvement of Meadow Land. (Changes in the Mouth of the Parret, p. 205.) *Letters, Papers, Bath [and W. Engl.] Soc.* vol. v. p. 201.

1791.

Armstrong, M. J. An Essay on the Contour of the Coast of Norfolk; But more particularly as it relates to the Marum-Banks and sea-breaches, So loudly and so justly complained of. Pp. 18. 4to. *Norwich.*

1792.

Brograve, Sir B. Account of Sea-Breaches between Yarmouth and Happisburgh. 4to. *Norwich.*

1796.

Anon. [Submerged Forest at Thornbeck Pool, Lancashire.] *Gentleman's Mag.* vol. 66, pt. 2, pp. 549–551, pl. II. fig. 1.

1799.

Correa de Serra, Dr. J. On a Submarine Forest on the East Coast of England (Lincolnshire). *Phil. Trans.* vol. lxxxix. no. 481, p. 145.

1804.

Gilpin, Rev. W. Observations on the Coasts of Hampshire, Sussex and Kent, relative chiefly to Picturesque Beauty . . . (Retirement of Sea; Work of Sea on Coasts, pp. 60–65.) 8o. *Lond.*

Pape, Rev. D. An Account of a simple and easy Means by which Rye Harbour was restored. *Trans. Soc. Arts,* vol. xxii. pp. 245–251.

1811.

Luc, J. A. De. Geological Travels. Translated from the French MS. Vol. ii. refers to waste of coast (Suffolk). 8o. *Lond.*

1814.

C[urteis], E. J. Letter on a Submarine Forest in Pevensey Level. *Gent. Mag.* vol. lxxxiv. pt. 2, p. 128.

1816.

Englefield, Sir H. A Description of the Principal Picturesque Beauties, Antiquities, and Geological Phenomena of the Isle of Wight. With additional Observations on the Strata of the Island, and their Continuation in the adjacent Parts of Dorsetshire. By T. Webster. (Chap. ii. Coast. Chines, pp. 83–86. Undercliff, pp. 129, &c.) 4to. *Lond.*

Horner, L. Sketch of the Geology of the South-Western Part of Somersetshire. (Coast, pp. 340, 341, 379–384.) *Trans. Geol. Soc.* vol. iii. p. 338.

Stephenson, R. [? Stevenson.] Observations upon the Alveus or General Bed of the German Ocean and British Channel [and on the Encroachments of the Sea on the Land]. *Mem. Wernerian Soc.* vol. ii. p. 464; *Ann. Phil.* vol. viii. p. 173; and (in 1817) *Phil. Mag.* vol. xlix. p. 412.

1817.

Fussell, L. A Journey round the Coast of Kent. 8o. *Lond.*

1818.

Paris, Dr. J. A. On a recent Formation of Sandstone, occurring in various Parts of the Northern Coasts of Cornwall. [Notes incursion of sand from sea.] *Trans. R. Geol. Soc. Cornwall*, vol. i. pp. 1–19.

1819.

Anderson, Capt. J. Some observations on the peculiarity of the Tides between Fairlight and the North Foreland, with an explanation of the supposed meeting of the Tides near Dungeness. *Phil. Trans.* vol. cix. p. 217.

1821.

Stevenson, R. On the Bed of the German Ocean or North Sea. *Mem. Wern. Soc.*, vol. iii. p. 44, and *Edin. Phil. Journ.* vol. iii. p. 44 (1820).

1822.

Boase, H. Observations on the Submersion of part of the Mount's Bay; and on the Inundation of Marine Sand on the north coast of Cornwall. *Trans. R. Geol. Soc. Cornwall*, vol. ii. p. 129.

Mantell, Dr. G. A. The Fossils of the South Downs; or Illustrations of the Geology of Sussex. (Submerged Forest, p. 288. Effects of the Ocean, 292, &c.) 4to. *Lond.*

Young, Rev. G., and J. Bird. A Geological Survey of the Yorkshire Coast. (Submerged Forest, &c. pp. 30, &c.) Ed. 2, in 1828. 4to. *Whitby.*

1824.

Roberts, G. The History and Antiquities of Lyme Regis and Charmouth. Ed. 2, in 1834.

1825.

Sedgwick, Rev. Prof. A. On the Origin of Alluvial and Diluvial Formations. *Ann. Phil.* ser. 2, vol. ix. p. 241.

1826.

De la Beche, [Sir] H. T. Notice of Traces of a Submarine Forest at Charmouth, Dorset. *Ann. Phil.* ser. 2, vol. xi. p. 143.

Robberds, J. W. Geological and Historical Observations on the Eastern Vallies of Norfolk. 8o. *Lond.* and *Norwich.*

1827.

Barham, Dr. T. F. Some Arguments in support of the opinion that the Iktis of Diodorus Siculus is St. Michael's Mount. [Notes buried forest.] *Trans. R. Geol. Soc. Cornwall*, vol. iii. pp. 86–112.

Boase, Dr. H. S. On the Sand-Banks of the Northern Shores of Mount's Bay. *Trans. R. Geol. Soc. Cornwall*, vol. iii. p. 166.

Carne, J. On the singular state of some Ancient Coins lately found in the Sands of Hayle; and, On the evidence deducible from them relative to the period of the earliest deposition of sand on the Northern Coast of Cornwall. *Trans. R. Geol. Soc. Cornwall*, vol. iii. p. 136.

HAWKINS, J. On the Changes which appear to have taken place in the primitive form of the Cornish Peninsula. *Trans. R. Geol. Soc. Cornwall,* vol. iii. p. 1.

ROBBERDS, J. W. Reply to Mr. R. C. Taylor's Remarks on the Hypothesis of Mr. Robberds on the former Level of the German Ocean. *Phil. Mag.* ser. 2, vol. ii. pp. 192, 271.

TAYLOR, R. C. On the Geology of East Norfolk; with Remarks upon the Hypothesis of Mr. Robberds, respecting the Former Level of the German Ocean. *Phil. Mag.* ser. 2, vol. i. pp. 277, 346, 426.

—— On the Natural Embankments formed against the German Ocean, on the Norfolk and Suffolk Coast, and the Silting up of some of its Estuaries. *Phil. Mag.* ser. 2, vol. ii. p. 295.

—— On the Geological Features of the Eastern Coast of England, and Concluding Remarks on Mr. Robberds's Hypothesis. *Ibid.* p. 327.

—— These three reprinted together, with additions.

1828.

STEVENSON, R. Remarks upon the Wasting Effects of the Sea on the shore of Cheshire, between the rivers Mersey and Dee. *Edin. New Phil. Journ.* vol. iv. p. 386.

1829.

MOORE, Rev. T. The History of Devonshire. (Changes on the Coast, p. 36.) 4to. *Lond.*

PHILLIPS, Prof. J. Illustrations of the Geology of Yorkshire. . . . Pt. I. The Yorkshire Coast (chaps. viii.–xi. Coast). Ed. 2, in 1835. Ed. 3, in 1875. 4to.

1830.

DE LA BECHE, [Sir] H. T. Notes on the Formation of extensive Conglomerate and Gravel Deposits. [Refers to the Chesil Beach, Shoreham, and Axmouth.] *Phil. Mag.* ser. 2, vol. vii. p. 161. Reprinted in his 'Geological Notes.'

HALL, R. C. An Essay on the Rights of the Crown and the Privileges of the Subject in the Sea Shores of the Realm. 8o. *Lond.* Ed. 2, by R. L. LOVELAND, in 1875.

LYELL, [Sir] C. Principles of Geology, vol. i. 8vo. *London.* (Loss of land, sand-dunes, silting up of estuaries, pp. 266–284, 300, 301, 306–308; and silting up of sea, pp. 266–284, 306–308.) Many later editions.

1831.

DE LA BECHE, [Sir] H. T. A Geological Manual. (Action of Sea on Coast, pp. 70–83. Submarine Forests, 143, &c.) 12mo. *Lond.* Ed. 2, in 1832, Ed. 3, 8vo. in 1833.

1832.

ROGERS, Rev. J. Notice of Wood and Peat found below high water-mark on the beach at Mainporth, in Cornwall. *Trans. R. Geol. Soc. Cornwall,* vol. iv. p. 481.

YATES, J. A Notice of a Submarine Forest in Cardigan Bay. *Proc. Geol. Soc.* vol. i. no. 28, p. 407.

1833.

ANON. The Storm; with Reflections and Admonitions on its disastrous Effects upon the Norfolk Coast. 8o. *Norwich.*

MANTELL, Dr. G. A. The Geology of the South-east of England. (Submerged Forests, p. 18. Encroachments of Sea, p. 23.) 8o. *Lond.* Much the same as the work of 1822.

PARISH, [Sir] W. [Submerged Forest, St. Leonards.] *Proc. Geol. Soc.* vol. ii. no. 33, p. 3.

PARRY, J. D. An Historical and Descriptive Account of the Coast of Sussex. . . . (Waste of land described.) 8o. *Lond.*

WOODWARD, S. An Outline of the Geology of Norfolk. 4to. and 8o. *Norwich.*

1834.

PALMER, H. R. Observations on the Motion of Shingle Beaches. [Folkestone and Dover.] *Phil. Trans.* vol. cxxiv. p. 567.

1835.

WALKER, W. Lecture on Geological Changes resulting from Meteorological Agency. [Dover Strait.] *S. Devon Monthly Museum*, vol. v. pp. 96, 136.

1836.

ROSE, C. B. A Sketch of the Geology of West Norfolk. *Phil. Mag.* ser. 3, vol. viii. p. 28. (Submarine Forest, p. 37.)

1837.

ANON. (A Naval Officer.) A Brief History of Dover and Ramsgate Harbours, with a Description of the coast between Dungeness and the Isle of Thanet. 8o. *Ramsgate.*

LUXMOOR, Lieut. Description of the Groins erected on the Coast of Sussex, for preventing Encroachments of the Sea. *Papers Corps R. Eng.* vol. i. p. 48. (? Ed. 2 in 1844.)

REID, Lt. Col. Description of the Concrete Sea Wall at Brighton, with the Groins which defend the foot of it. *Papers Corps R. Eng.* vol. i. p. 43.

RICHARDSON, W. Observations upon the Chronological Arrangement of Fossiliferous Deposits. . . . (Notes waste of Kentish Coast.) *Mag. Nat. Hist.* vol. x. p. 122.

1838.

CLARKE, Rev. W. B. On the peat bogs and submarine forests of Bourne Mouth, Hampshire, and in the neighbourhood of Poole, Dorsetshire. *Proc. Geol. Soc.* vol. ii. no. 54, p. 599.

CUBITT, [Sir] W. Report on plans . . . for forming a Harbour at Hastings, with the Report and Plans (by Col. WILLIAMS) annexed. Fol. *Hastings.*

DENHAM, Capt. On the Tidal Capacity of the Mersey Estuary—the Proportion of Silt held in solution . . . the Excess of Deposit upon each Reflux, and the consequent Effect produced by the Matter thus detected in its transit, and measured at its lodgement, on the banks in Liverpool Bay. *Rep. Brit. Assoc.* 1837, *Sections*, p. 85.

ELLIOT, [Admiral], G., and [Admiral Sir] E. W. PARRY. Report and Memorial on the State of Folkestone Harbour. *Parliamentary Papers*, vol. xlv. 5 pp. [Notes accumulation of shingle.]

HAM, J. On the Mud deposited by the Tidal Waters of the Severn, Usk, and Avon, and other phænomena connected with the Waters of these Rivers. *Rep. Brit. Assoc.* 1837, *Sections*, p. 76.

Reid, Lt.-Col. Further Observations on the moving of the Shingle of Beach along the Coast. *Papers Corps R. Eng.* vol. ii. p. 128.

Rooke, J. Geology as a Science applied to the Reclamation of Land from the Sea, the Construction of Harbours . . . 8o. *Lond.* Ed. 2, in 1840.

Williams, Col. [? Lt. Col. J. H.]. Observations on Mr. Cubitt's Report [above]. Fol. *Hastings.*

1839.

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Murchison, [Sir] R. I. The Silurian System. . . . (Blown Sands, Submerged Forests, &c. [of Welsh Coast], pp. 562–564). 4to. *Lond.*

Williams, Lt.-Col. J. H. Memoir relative to the course of the Shingle on the Coasts of Sussex and Kent, and the Laws by which it is governed. *Civ. Eng. Architect's Journ.* vol. ii. p. 126.

1840.

Conybeare, Rev. W. D. Extraordinary Landslip and Great Convulsion of the Coast of Culverhole Point, near Axmouth. *Edin. New Phil. Journ.* vol. xxix. p. 160.

Hutchinson, P. O. A Guide to the Landslips near Axmouth. 12mo. *Sidmouth.*

Poulson, G. The History and Antiquities of the Seigniory of Holderness. 2 vols. *Hull* (? 1840 and 1841).

Rickman, W. Earth Falls at the Undercliff in the Isle of Wight. *Proc. Inst. C.E.* vol. i. p. 35.

Roberts, G. An Account of the Mighty Landslip at Dowlands and Bindon, near Lyme Regis, December 25th, 1839. 8o. *Lyme.* (5 editions.)

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HAMILTON, H. Rights of Foreshore. *Trans. Inst. Surveyors,* vol. xviii. pt. vi. p. 179. (Discussion, p. 198.) See also *Professional Notes Inst. Surveyors,* vol. i. p. 26.

ORMEROD, G. W. Old Sea-Beaches at Teignmouth, Devon. *Quart. Journ. Geol. Soc.* vol. xlii. pp. 98–100.

PRESTWICH, Prof. J. Geology Chemical, Physical, and Stratigraphical. (Refers to Coast Changes, pp. 98–102.) Vol. i. 8o. *Oxford.*

WHITAKER, W., and G. DOWKER. Excursion to . . . . Reculvers, Pegwell Bay, and Richborough. *Proc. Geol. Assoc.* vol. ix. no. 4, p. 168.

WOODWARD, H. B. Excursion to . . . . Burton Bradstock, Bridport Harbour, and Eype (pp. 204–206). *Proc. Geol. Assoc.* vol. ix. no. 4, p. 200.

? date.

MUMFORD, Rev. G. Geology . . . . of Hunstanton, in 'Hunstanton and its Neighbourhood.' 8o. *Lynn* and *Lond.* Ed. 4 in 1874. Ed. 6 in 1879. Ed. 7 in 1881.

Report of the Committee, consisting of Professor RAY LANKESTER, Mr. P. L. SCLATER, Professor M. FOSTER, Mr. A. SEDGWICK, Professor A. M. MARSHALL, Professor A. C. HADDON, Professor MOSELEY, *and* Mr. PERCY SLADEN (*Secretary*), *appointed for the purpose of arranging for the occupation of a Table at the Zoological Station at Naples.*

IN the Report read last year at Montreal, it was announced that a scheme was on foot for the building of a large physiological laboratory in connection with the Zoological Station at Naples, and for the purchase of a new sea-going steamer, to be equipped as a floating laboratory. Your Committee are now able to report that both these projects are steadily advancing towards attainment. For the physiological laboratory the Municipality of Naples has made a grant of 400 square mètres of ground, and the Italian Parliament has voted the sum of 50,000 lire towards the cost of building. Work is already commenced, and the plans show that the new laboratory will form an extension of the present handsome station, and will be carried out in the same style of architecture.

In addition to this assistance from the Italian Government, a Union of the maritime provinces of South Italy is about to be formed for the purpose of contributing towards the cost of the new laboratory, and of maintaining two tables there for the use of natives of the provinces concerned.

The exceptional advantages that a physiological laboratory connected with the Zoological Station will afford to investigators are too obvious to need recapitulation here; and Professor Dohrn will receive the congratulations of all biologists upon the patience with which his scheme, after years of anxious development, has been matured, and upon the success with which it has now been rewarded.

The new steamship, which it is hoped will shortly be in the possession of the station, will form a further and no less important addition to the capabilities of the establishment. The undertaking is in the hands of an influential committee in Germany, organised for the purpose of collecting subscriptions, and by whom the vessel will be presented to the station. It is intended that the steamer should be of 300 to 400 tons burden, with engines of 150 to 200 horse-power, and be fitted up in all respects as a floating laboratory. With such a vessel it will be perfectly practicable to remain weeks or months in any desired locality, and distance from home will be no obstacle, as the naturalists will live and work on board.

Biologists will call to mind numberless difficult problems that it will be possible by this means to investigate with every prospect of successful solution, which hitherto have remained unapproachable. The imaginary sketch of what might readily be accomplished by means of the floating laboratory, given by Professor Dohrn in a recently published report on the progress and prospects of the Zoological Station, reads almost like a naturalist's dream—a scientist's castle in the air—instead of the calm *résumé* of what will be reasonably possible in the near future so soon as the station is in possession of this veritable castle on the sea.

Concurrent with these greater strides of the Zoological Station, improvements in the general management, in methods of work, and in instruments of research are constantly being made, the details of which

would be too numerous to mention in this place. The general efficiency of the establishment is so well known that it will suffice to say that the whole organisation of the station is in a state of active and prosperous vitality. The best evidence of this is furnished by the accompanying lists: (1) of the naturalists who have occupied tables during the past year, and (2) of the publications resulting from work carried out at the station.

The General Collections.—Additions have been again received from Captain Chierchia, who has, since the last Report, sent two collections of specimens from the Pacific and Indian Oceans. Other collections have likewise been received from Lieutenant Cercone, Lieutenant Orsini, and Lieutenant Colombo, from the Atlantic, the Red Sea, and the Mediterranean respectively.

Some of the material previously obtained by Captain Chierchia has already been utilised by Count Béla Haller in a paper on the Molluscan kidney, recently published; and the same author is at present preparing a monograph on the Patellæ. In like manner, the Pteropoda have been investigated by Dr. Boas of Copenhagen, whose monograph upon the subject is now in the press.

The Publications of the Station.—The scientific importance and artistic beauty of these works are now so well known that comment would be superfluous.

1. Of the 'Fauna und Flora des Golfes von Neapel,' the following monograph has been published since the last Report:—XI. A. Lang, 'Polycladæ' (2te Hälfte: the complete work 688 pp., 39 plates).

The following works are in the press:—K. Brandt, 'Coloniebildende Radiolarien.' J. Fraipont, 'Polygordius.'

Monographs by G. von Koch on 'Gorgoniidæ,' and by P. Falkenberg on 'Rhodomeleæ,' will also shortly appear, the plates being now in the press.

2. Of the 'Mittheilungen aus der zoologischen Station zu Neapel,' vol. v. (580 pp., 32 plates), is complete, and contains numerous papers written in English; of vol. vi., parts i. and ii. are published.

3. The 'Zoologischer Jahresbericht' for 1883 (1,324 pp.) is published. The general arrangement and treatment of subjects are the same as mentioned in the previous Report. Sections 1 and 2 are edited by Drs. Paul Mayer and W. Giesbrecht, and sections 3 and 4 by Dr. Paul Mayer. The 'Bericht' for 1884 is in the press.

4. Of the Guide to the Aquarium, printed in German, English, Italian, and French, a second German edition has just been published, and a second Italian one will shortly be required. A supplement has also been printed in each of the four languages, in which the actual contents of every tank are enumerated, and references are given to the pages of the Guide and the accompanying illustrations. By this means the finding of any special animal, as well as the intelligent perusal of the Guide by the general public, is greatly facilitated.

Extracts from the General Report of the Zoological Station.—The usual lists and details, courteously furnished by the officers of the station, will be found at the end of this Report, and bear testimony to the constantly increasing activity of the station.

The British Association Table.—Since the last Report, the table has been occupied by Mr. Wm. E. Hoyle, who, although limited in time, was enabled to prosecute researches on the embryology of the Cephalopoda,

and to collect material from which important results may be expected. The report forwarded by Mr. Hoyle is appended.

An application for permission to use the table during the coming year has already been received, and others are expected. In view of these anticipations, and of the exceptional advantages afforded by the British Association table in the Zoological Station at Naples, your Committee most confidently recommend the renewal of the grant (100*l.*) for the ensuing year.

I. *Report on the Occupation of the Table, by Mr. William E. Hoyle.*

I reached Naples on April 6, 1885, and left on the 28th of the same month. In so short a time it was obviously impossible to make anything of the nature of a complete investigation in a subject of such magnitude and difficulty as the embryology of the Cephalopoda; it seemed, therefore, that the opportunities afforded me could best be utilised by collecting material for subsequent examination.

Of this I had an abundant and immediate supply, thanks to the kindly forethought of your Secretary, who had given notice to the authorities of the station of the nature of the work I had undertaken, so that they had a quantity of ova ready for my use.

The greater part of my time was spent in extracting embryos from the egg and preserving them in various fluids, and a fairly complete series of developmental stages of *Loligo* and a good many embryos of *Sepia* were thus obtained. When the young Cephalopods have reached a stage at which the rudiments of the arms are clearly visible, it is moderately easy, after a little practice, to extricate them by making an incision into the egg-membrane with a fine scalpel; but previously to this period they so nearly occupy the whole interior of the egg that it is almost impossible to obtain them uninjured.

A quantity of such eggs I preserved whole by a method suggested to me by Dr. Jatta, who is at work upon a monograph of the Cephalopoda of the Bay of Naples.

The strings of eggs are placed whole in weak solution of chromic acid (about 0·25 per cent.) for a few hours, and then in distilled water for twenty-four hours, after which they are preserved in alcohol. The embryos can then be extracted much more readily than when fresh.

Some time was devoted to examining and drawing the embryos in the fresh condition, and in watching the process of segmentation in *Loligo* and *Sepia.* I observed the presence of the 'Richtungsbläschen' in the former, which, so far as I am aware, has only been noted in a Russian memoir on the development of *Sepiola* by Ussow.

A number of blastoderms in process of segmentation were preserved according to a method proposed by Ussow, for the knowledge of which I am indebted to Dr. Edward Meyer, who kindly translated it for me from the original.

The egg, without removal of the membranes, is placed in 2 per cent. solution of chromic acid for two minutes, and then in distilled water, to which a little acetic acid (one drop to a watchglassful) has been added, for two minutes longer. If an incision be now made into the egg-membrane the yolk flows away and the blastoderm remains; if any yolk still cling to it, it may be removed by pouring away the water and adding more.

The blastoderms thus prepared show, when appropriately stained, fine karyokinetic figures, of which I hope shortly to publish an account.

The reduction of the collected embryos to serial sections and their examination will of course occupy some time, but I hope in a few months to prepare some account of the results obtained from them.

In conclusion, I have to express my thanks to the Committee for granting me the use of their table, as well as to the authorities of the Zoological Station for their kindness and courtesy to me during my work.

II. *A List of Naturalists who have worked at the Station, from the end of June* 1884 *to the end of June* 1885.

Number on List	Naturalist's Name	State or University whose Table was made use of	Duration of Occupancy	
			Arrival	Departure
287	Dr. G. Jatta	Italy	July 1, 1884	Dec. 31, 1884
288	Dr. M. Giuliani	„	„ 7, „	Aug. 15, „
289	Prof. F. Gasco	„	Aug. 11, „	Oct. 25, „
290	Prof. C. Emery	„	„ 12, „	„ 26, „
291	Dr. C. Crety	„	„ 14, „	Sept. 7, „
292	Dr. W. J. Vigelius	Holland	Sept. 8, „	Dec. 20, „
293	Dr. F. Raffaele	Italy	Oct. 18, „	—
294	Mr. M. Jaquet	Switzerland	Nov. 13, „	Mar. 11, 1885
295	Dr. A. D. Onody	Hungary	„ 21, „	Feb. 4, „
296	Dr. F. Albert	Prussia	„ 28, „	April 1, „
297	Dr. W. Repiachoff	Russia	Dec. 21, „	June 25, „
298	Dr. G. Jatta	Italy	Jan. 1, 1885	—
299	Ufficiale A. Colombo	Italian Navy	„ 11, „	May 11, 1885
300	Dr. Ch. Dolley	Philadelphia	„ 15, „	June 18, „
301	Dr. Paulicki	Strassburg	Feb. 4, „	Mar. 7, „
302	Prof. Benecke	Prussia	„ 6, „	April 7, „
303	Dr. Cl. Hartlaub	Hamburg	„ 15, „	June 25, „
304	Dr. E. Ziegler	Baden	„ 26, „	April 15, „
305	Stud. von Oefele	Bavaria	March 1, „	„ 14, „
306	Dr. E. Rohde	Prussia	„ 8, „	May 25, „
307	Dr. A. Koenig	Own table	„ 8, „	—
308	Sig. E. Stassano	Italy	„ 13, „	—
309	Dr. Thallwitz	Baden	„ 13, „	May 3, 1885
310	Prof. Todaro	Italy	„ 13, „	April 4, „
311	Prof. Merkel	Prussia	„ 15, „	„ 8, „
312	Stud. T. Wenckebach	Holland	„ 16, „	—
313	Dr. R. Altmann	Saxony	„ 20, „	April 15, 1885
314	Mr. Wm. E. Hoyle	British Association	April 6, „	„ 27, „
315	Prof. Carnoy	Belgium	„ 8, „	June 25, „
316	Dr. Gilson	„	„ 8, „	„ 25, „
317	Dr. J. Walther	Academy, Berlin	„ 12, „	„ 28, „
318	Dr. W. Patten	Zoological Station	„ 14, „	—
319	Dr. Schirlitz	Prussia	„ 17, „	June 20, 1885
320	Comand. de Simone	Italian Navy	„ 18, „	May 1, „
321	Prof. Della Valle	Italy	June 22, „	—

III. *A List of Papers which have been published in the year* 1884 *by the Naturalists who have occupied Tables at the Zoological Station.*

Dr. J. Frenzel . . . Ueber die Mitteldarmdrüse der Crustaceen. 'Mittheil. Zool. Station Neapel,' Bd. V., 1884.

Dr. E. Wilson . . . The Mesenterial Filaments of the Alcyonaria. 'Mittheil. Zool. Station Neapel,' Bd. V., 1884.

Dr. F. Blockmann . Die im Golfe von Neapel vorkommenden Aplysien. 'Mittheil. Zool. Station Neapel,' Bd. V., 1884.

Prof. G. Fritsch . .	Beiträge zur Embryologie vom Torpedo: Bericht über die Fortsetzung der Untersuchungen an elektrischen Fischen. 'Archiv für Anatomie u. Physiologie,' Physiol. Abtheilung, Jahrgang 1884.
Sig. E. Stassano . .	L'action du Curare dans la série animale. 'Comptes Rendus de la Société de Biologie de Paris,' 1884.
" . . .	La Generazione spontanea ecc. 'Giornale Internazionale delle Scienze Mediche,' Anno VI., 1884.
Prof. R. Kossmann .	Neueres über Cryptonisciden. 'Sitzungsberichte Kön. Preuss. Akad. d. Wissensch.' Bd. 22, 1884.
Prof. A. Della Valle .	Sul Ringiovanimento delle Colonie di Diazona violacea. 'Rendic. della R. Accademia delle Scienze ecc. di Napoli,' 1884.
Dr. C. Keller . . .	Mittheilungen über Medusen. 'Recueil Zoologique Suisse,' t. i. 1844.
Prof. H. Grenacher .	Abhandlungen zur vergleichenden Anatomie des Auges. I. Die Retina der Cephalopoden. 'Abhandlungen Naturf. Ges. Halle,' Bd. 16, 1883.
Prof. C. E. Eberth .	Die Befruchtung des thierischen Eies. 'Fortschritte der Medicin,' Bd. 2, 1884.
MM. E. van Beneden et Ch. Julin	La segmentation chez les Ascidiens dans ses rapports avec l'organisation de la larve. 'Bull. Acad. Belg.' 1884.
Dr. L. Oerley . . .	Ueber die Athmung der Serpulaceen, etc. 'Naturhist. Hefte, Budapest,' Vol. viii. 1884.
Prof. A. G. Bourne .	Contributions to the Anatomy of the Hirudinea. 'Quart. Journ. Microscop. Science,' 1884.
Prof. A. M. Marshall	On the Nervous System of Antedon rosaceus. *Ibid.*
Dr. M. von Brunn .	Weitere Funde von zweierlei Samenkörperformen in demselben Thiere. 'Zool. Anzeiger,' 1884.
Prof. C. Emery . .	Les taches brillantes de la Peau chez les Poissons du Genre Scopelus. 'Archives Italiennes,' t. v. 1884.
" . . .	Intornò alle macchie splendenti della pelle nei pesci del genere Scopelus. 'Mittheil. Zool. Station Neapel,' Bd. V., 1884.
Dr. A. Garbini . . .	'Manuale per la Tecnica moderna del Microscopio ecc.' Verona, 1884.
Dr. von Sehlen . .	Studien über Malaria. 'Fortschritte der Medicin,' Bd. 2, 1884.
Dr. T. Weyl . . .	Physiologische und chemische Studien am Torpedo. 'Archiv f. Anatomie und Physiologie,' Physiol. Abtheilung, 1883–4; 'Zeitschrift für physiol. Chemie,' 1883.
Dr. B. Uljanin . . .	Die Arten der Gattung Doliolum im Golfe von Neapel. Monographie X. der 'Fauna u. Flora des Golfes von Neapel,' herausgegeben von der Zool. Station, Leipzig, 1884.
Dr. J. Fraipont . .	Recherches sur le système nerveux central et périphérique des Archiannélides. 'Archives de Biologie,' t. v. 1884.
" . . .	Le rein céphalique du Polygordius. 'Bull. Acad. Roy. de Belgique,' 3 Sér. t. viii. 1884.
Mr. S. Harmer . . .	On a Method for the Silver Staining of Marine Objects. 'Mittheil. Zool. Station Neapel,' Bd. V., 1884.
Dr. B. Sharp . . .	On the Vesical Organs in Lamellibranchiata. *Ibid.*
Dr. P. Schiemenz . .	Ueber die Wasseraufnahme bei Lamellibranchiaten und Gastropoden. *Ibid.*
Prof. G. Entz . . .	Ueber Infusorien des Golfes von Neapel. *Ibid.*
Dr. J. W. Spengel .	Zur Anatomie des Balanoglossus. *Ibid.*
Dr. J. Beard . . .	On the Life-History and Development of the Genus Myzostoma. *Ibid.*
Dr. G. Klebs . . .	Ein kleiner Beitrag zur Kenntniss der Peridineen. 'Botanische Zeitung,' 1884.
Dr. G. Berthold . .	Die Cryptonemiaceen. Monographie XII. der 'Fauna u. Flora des Golfes von Neapel,' herausgegeben von der Zoolog. Station, 1884.

IV. *A List of Naturalists to whom Specimens have been sent, from July* 1, 1884, *to the end of June* 1885.

					Lire c.
1884.	July	2	Naturalien-Cabinet, Stuttgart	Collection	595·20
	„	5	Mr. A. Heath, London	Physalia	24·90
	„	5	Nat. Hist. Museum, Groningen.	Corallium rubrum	105·50
	„	5	Dr. Rawitz, Berlin	Mollusca	10·30
	„	9	Dr. Hundeshagen, Leipzig	Aplysina	7·25
	„	11	Prof. H. N. Moseley, Oxford	Corallium, Sipunculus	114·20
	„	12	Dr. v. Brunn, Leipzig	Tortoise-shell	10·
	„	16	Herr H. Putze, Hamburg	Argonauta	17·90
	„	17	Prof. Gierke, Breslau	Carcharias, Tethys.	44·75
	„	17	Prof. Kupfer, Munich	Embryos of Torpedo	12·65
	„	17	Prof. Kollmann, Bâle	Embryos of Torpedo	38·30
	„	23	Dr. Grütter, St. Gallen	Collection	149·55
	„	23	Donough School, Baltimore	Collection	150·85
	„	23	Williams Coll., Mass.	Collection	172·55
	Aug.	1	Mr. G. E. Mason, London	Rana esculenta	7·90
	„	1	Dr. Jickeli, Hermannstadt	Antedon rosacea	12·40
	„	7	Anat. Institut, Freiburg	Mustelus, Scyllium	36·
	„	7	Dr. B. Hatscheck, Linz	Amphioxus	13·
	„	8	Dr. John Beard, Manchester	Embryos of Torpedo	38·75
	„	10	Herr A. Wenke, Jaromierz	Cœlent., Vermes	31·05
	„	10	Mr. Charles Jeffreys, Tenby	Mollusca	17·75
	„	11	Prof. Friant, Nancy	Corallium	43·30
	„	13	Mr. Puls, Ghent	Corallium	53·20
	„	17	Prof. Hoffmann, Leyden	Collection	300·
	„	27	Prof. N. Kowalewsky, Kasan	Torpedo	15·05
	„	27	Mr. J. B. Jeaffreson, London	Echinodermata	35·65
	„	27	Herr H. Putze, Hamburg	Cassiopeia	30·80
	„	29	Prof. A. G. Bourne, London	Corallium	51·25
	„	29	Mr. Weldon, Cambridge	Corallium	21·
	„	30	H.E. the Ambass. von Keudell, Rome	Collection	53·
	Sept.	6	Prof. Grenacher, Halle	Corallium, Amphioxus	52·80
	„	17	Prof. Richiardi, Pisa	Collection	269·95
	„	17	Dr. Singer, Regensburg	Corallium	53·05
	„	18	Mr. Marie, Paris	Collection	157·20
	„	19	Dr. J. Blaue, Halle	Collection	44·30
	„	20	Dr. Goronowitsch, Heidelberg	Algæ	15·20
	„	22	Istituto Tecnico, Arezzo	Corallium, Tethya	22·45
	„	26	Prof. Ehlers, Göttingen	Collection	134·40
	Oct.	10	Dr. Reinhold, Odessa	Algæ	13·20
	„	16	Zool. Inst., University, Berlin	Collection	256·80
	„	19	Dr. Meffert, Breslau	Corallium	27·
	„	19	Dr. A. Batelli, Florence	Fins of Motella	6·95
	„	22	National Museum, Budapest	Corallium	52·
	„	22	Herr Wettstein, Küssnacht	Scorpio	5·
	„	24	Mr. T. Bolton, Birmingham	Collection	78·40
	„	25	Prof. Claus, Vienna	Peneus, Stenopus, &c.	49·90
	„	29	Dr. Honegger, Zürich	Scyllium, Myliobatis, &c.	54·55
	Nov.	5	Prof. Mitsukuri, Tokio, Japan	Collection	377·45
	„	5	Prof. C. Emery, Bologna	Corallium	42·
	„	10	Morphol. Labor., Cambridge	Holothuria, Sepia, &c.	246·50
	„	12	Mr. Puls, Ghent	Collection	283·
	„	12	Dr. Simroth, Leipzig	Corallium	33·
	„	12	Dr. Mösch, Zürich	Corallium	27·55
	„	12	Prof. A. G. Bourne, London	Amphioxus	8·65
	„	12	Mr. Davidson, Brighton	Brachiopoda	12·65
	„	13	Dr. Mendelsohn, Posen	Various	24·85
	„	21	Mr. A. Pennington, Bolton	Collection	329·15
	„	21	Prof. Stepanoff, Charkoff	Corallium, &c.	92·30
	„	22	Zool. Institut, Würzburg	Embryos of Sharks	54·10
	„	24	Dr. J. W. Spengel, Bremen	Various	113·80

					Lire c.
1884.	Dec.	4	Dr. A. Vayssière, Marseilles	Bulla striata	2·80
	„	4	Prof. Burbach, Gotha	Mollusca	75·
	„	8	Mr. E. Marie, Paris	Sepia	7·90
	„	10	Prof. F. Mercanti, Arezzo.	Various	27·70
	„	10	Conte Peracca, Turin	Lacerta muralis	15·50
	„	11	Mr. R. Damon, Weymouth	Collection	300·25
	„	15	Dr. C. Crety, Rome	Various	6·65
	„	20	Dr. Vigelius, Hague	Collection	204·80
	„	21	Mr. Vallentin, Leytonstone	Various	38·50
	„	22	Dr. Escherich, Munich	Collection	70·
	„	23	Prof. Kossmann, Heidelberg	Sacculina	14·05
	„	23	Prof. Wagner, St. Petersburg	Doliolum	4·
	„	23	Mr. Chas. Jeffreys, Tenby	Mollusca	40·30
1885.	Jan.	3	Rev. A. M. Norman, Durham	Collection	377·50
	„	4	Anat. u. Embr. Inst., Budapest	Pelagia, Salpa	18·05
	„	6	Prof. A. G. Bourne, London	Amphioxus	10·80
	„	6	Zool. Inst., Würzburg	Natica Josephinia	4·95
	„	7	Dr. Krukenberg, Jena	Scyllium, &c.	13·50
	„	7	Dr. J. Mac-Leod, Ghent	Various	39·80
	„	9	Gymnasium, Bartenstein	Various	99·35
	„	9	Dr. John Beard, Manchester	Embryos of Torpedo, &c.	14·85
	„	13	Mr. F. Cunningham, Edinburgh	Balanoglossus	11·50
	„	15	Prof. O. Burbach, Gotha	Collection	181·40
	„	15	Mr. A. Eloffe, Paris	Collection	197·40
	„	16	Dr. Hoek, Leyden	Scalpellum	4·25
	„	17	Prof. Giglioli, Florence	Luvarus	60·
	„	20	Prof. D'A.W. Thompson, Dundee	Collection	51·45
	„	24	Prof. L. v. Graff, Graz	Collection	296·
	„	25	Dr. A. Andres, Milan	Actinia	11·30
	„	27	Prof. E. R. Lankester, London	Various	6·10
	„	27	Miss Petrovski, Geneva	Various	11·50
	Feb.	2	Mr. O. Hann, Dresden	Actinia	10·50
	„	4	Dr. Spangenberg, Munich	Collection	262·65
	„	4	Dr. Honegger, Zürich	Brains of Dogfish	10·65
	„	5	Mr. J. R. Bradford, London	Annelida	24·95
	„	9	Prof. Leenhardt, Montauban	Various	55·10
	„	10	Prof. Grenacher, Halle	Pecten	12·80
	„	10	Società Tecnica, Florence	Collection	62·40
	„	11	Herr G. Krause, Glogau	Various	22·70
	„	12	Scuola d'Agricoltura, Portici	Collection	109·35
	„	18	Mr. L. Dreyfus, Wiesbaden	Collection	189·20
	„	25	Mr. E. Marie, Paris	Torpedo, Corallium	90·20
	„	25	Prof. H. Blanc, Lausanne	Various	77·
	„	25	Morphol. Labor., Cambridge	Ascidia, Amphioxus	114·70
	„	25	Mr. W. P. Sladen, Ewell	Various	18·15
	„	27	Dr. A. Batelli, Perugia	Collection	118·65
	„	28	Museum of Nat. History, Aarau	Collection	375·55
	March	2	Prof. P. Pavesi, Pavesi	Siphonophora	116·
	„	3	Prof. R. Leuckart, Leipzig	Siphonophora	90·65
	„	3	Prof. E. R. Lankester, London	Siphonophora	92·85
	„	4	Dr. Th. Barrois, Lille	Various	15·25
	„	7	Mr. A. Meinecke, Milwaukee	Collection	160·65
	„	9	Prof. v. Marenzeller, Vienna	Collection	320·80
	„	10	Dr. L. Eger, Vienna	Collection	198·65
	„	11	Dr. Mendelsohn, Posen	Various	40·40
	„	15	Prof. Vogt, Geneva	Corallium	23·10
	„	15	Zool. Inst., Würzburg	Natica Josephinia	3·65
	„	22	Prof. Fano, Genoa	Amphioxus	3·05
	„	22	Dr. Krukenberg, Jena	Loligo	4·10
	„	28	Mr. Sanz de Diego, Madrid	Collection	1403·25
	„	28	Zoolog. Sammlung, Zürich	Collection	135·40
	„	29	Prof. Grassi, Catania	Various	77·75
	„	29	Dr. Bolau, Hamburg	Living animals	—

				Lire c.
1885.	March 31	Prof. Ussoff, Kasan	Torpedo, Carcharias, &c.	58·75
	April 1	Anat. u. Embr. Inst., Budapest.	Hexanchus	83·
	„ 13	Zool. Inst., University, Berlin	Collection	1175·15
	„ 13	Prof. Ehlers, Göttingen	Siphonophora	100·15
	„ 13	Dr. Th. Weyl, Berlin	Torpedo	40·
	„ 18	Mr. Vallentin, Leytonstone	Salpa	15·15
	„ 18	Prof. D'A.W. Thompson, Dundee	Collection	85·10
	„ 18	Società Tecnica, Florence	Collection	226·60
	„ 18	Prof. C. Chun, Königsberg	Collection	196·50
	„ 29	Dr. L. Kalvoda, Dettingen	Collection	163·20
	„ 30	Mr. G. L. Gulland, Edinburgh	Lophogaster	10·05
	„ 30	Dr. Aug. Müller, Frankfort o/M.	Collection	156·20
	May 3	Dr. A. Batelli, Perugia	Ascidia	30·
	„ 3	Prof. Frizzi, Perugia	Collection	300·
	„ 3	Prof. Grenacher, Halle	Eyes of Carinaria, &c.	12·55
	„ 3	Prof. F. Merkel, Königsberg	Torpedo	33·50
	„ 5	Prof. Bogdanoff, Moscow	Siphonophora, &c.	155·85
	„ 5	Dr. Altmann, Leipzig	Eggs of Scyllium	2·50
	„ 6	Prof. Fano, Genoa	Amphioxus	3·05
	„ 6	Mr. S. Brogi, Siena	Collection	55·80
	„ 6	Zool. Inst., Würzburg	Phascolosoma	4·50
	„ 12	Mr. E. Marie, Paris	Rhizostoma, &c.	26·65
	„ 14	Zool. Inst., Strassburg	Collection	202·30
	„ 14	Dr. Rohde, Breslau	Corallium, Agalma	10·
	„ 20	Dr. Örley, Budapest	Crustacea	219·70
	„ 20	Mr. Pedro Antiga, Barcelona	Various	58·65
	„ 25	Prof. Bergh, Copenhagen	Marsenia	7·25
	„ 26	Conte Peracca, Turin	Lacerta	16·
	„ 27	Zool. Inst., Würzburg	Various	30·90
	„ 27	Zool. Inst., Munich	Dentalium, Ciona	21·15
	„ 29	Soç. per l'Educaz. popolare, Naples	Collection	144·
	June 5	Prof. Pfeffer, Tübingen	Algæ	7·50
	„ 8	Herr L. Gerwig, Heidelberg	Various	27·20
	„ 8	Dr. Bolau, Hamburg	Living animals	—
	„ 9	Prof. Lütken, Copenhagen	Collection	304·70
	„ 10	Mr. E. Marie, Paris	Physalia, Torpedo	76·25
	„ 10	Mr. Holeczck, Kruszelnica	Various	123·80
	„ 10	Dr. John Beard, Manchester	Embryos of Dogfish	13·50
	„ 18	Prof. Frizzi, Perugia	Various	55·80
	„ 18	Dr. Krukenberg, Jena	Cartilage of Mustelus	8·25
	„ 18	Dr. Schirlitz, Danzig	Collection	115·85
	„ 18	Mr. R. Damon, Weymouth	Collection	421·95
	„ 19	Prof. Colasanti, Rome	Rhizostoma	10·40
	„ 23	Prof. Richiardi, Pisa	Collection	410·90
	„ 23	Dr. J. W. Spengel, Bremen	Collection	173·55
	„ 27	Dr. J. Walther, Munich	Argonauta, Beroe	11·
				17014·25

V. *A List of Naturalists to whom Microscopic Preparations have been sent, from the end of June* 1884 *to the end of June* 1885.

				Lire c.
1884.	July 22	Prof. Palmen, Helsingfors	34 preparations	34·50
	Dec. 18	Dr. Vigelius, Hague	17 „	25·
	„ 18	Gymnasium, Hague	14 „	15·
1885.	Jan. 17	Anat. u. Embr. Inst., Budapest	3 „	7·
	Feb. 5	Prof. Leenhardt, Montauban	24 „	42·
	„ 5	Dr. Mendelsohn, Posen	6 „	12·
	May 27	Mr. George Brook, Edinburgh	43 „	86·70
	„ 27	Zool. Inst., Univ., Strassburg	8 „	17·50
	June 4	Prof. Bogdanoff, Moscow	14 „	28·
				267·70

Report of the Committee, consisting of Professor McKendrick, Professor Struthers, Professor Young, Professor McIntosh, Professor Alleyne Nicholson, Professor Cossar Ewart, *and* Mr. John Murray (*Secretary*), *appointed for the purpose of promoting the establishment of a Marine Biological Station at Granton, Scotland.*

The Committee report that the sum of 100*l.* placed at their disposal has been expended in the maintenance and additional equipment of the Scottish Marine Station at Granton. The following report on the development and present condition of the station has been sent in to the secretary by Mr. J. T. Cunningham, the superintendent:

At the time of the last meeting of the British Association the laboratories and aquaria of the station were all contained in the floating establishment called the 'Ark.' Last autumn more spacious premises were acquired. These are situated on the shore not far above high-water mark, and only a few hundred yards to the east of the submerged quarry in which the ark was moored. The property when acquired consisted of a number of rough brick sheds surrounding a central yard, and had been used as a factory; it covers an oblong area about 147 feet in a direction parallel to the shore, by 78 feet in breadth. On the north side of the area now stands the building containing the laboratory and aquarium, the former occupying the upper storey, the latter the ground floor. The laboratory is divided into two parts by a partition, the western room serving principally as a museum. The building was constructed and the laboratory fitted in the autumn of last year. In the spring of the present year the system of aquaria was fitted up, the work having been commenced at the beginning of May and finished on June 17. The aquarium tanks are seven in number, and are constructed of wood. A row of five runs along the north side of the aquarium room; these are shallow, their dimensions being 8 feet by 6 feet by 1 foot 3 inches. They are arranged in a stair-like series, each being about 8 inches lower than its neighbour on the east side, and the water flows from the overflow-pipe of one to the other throughout the series. On the south side of the room are two deep tanks, each measuring 6 feet by 5 feet by 3 feet, and having the front partially formed of plate-glass.

The water to supply the aquarium tanks comes from a large reservoir, also of wood, fixed at a higher level than the roof of the aquarium room, in the shed to the east of the latter. The water overflowing from the aquarium tanks is delivered by means of indiarubber hose into a number of pits sunk into the ground; these are lined with cement, and roofed over in order to exclude dust and rain. They are situated at the west end of the central yard.

The circulation of sea water is maintained by a horizontal double-action pump, which is fitted up in a small building at the south-east corner of the premises. A suction pipe two inches in diameter connects the pump with the quarry, and opposite the pits before referred to the pipe is fitted with a stop-cock and hose coupling, so that the communica-

tion with the quarry may be shut off, and water pumped out of the low-level reservoir formed by the pits. The delivery pipe from the pump branches after some distance, one branch going to the high-level, the other to the low-level reservoir. The latter is used when it is required to pump water direct from the quarry to the low-level reservoir. The water is delivered into the deep aquarium tanks by four fine-glass jets. The highest shallow tank is supplied from an ordinary stop-cock, but there is also a pipe running along the wall at the back of the shallow tanks, fitted with a number of jets from which small vessels for isolation and experiment may be supplied.

The steam yacht *Medusa*, of fourteen tons burthen, which was built for the Station at its institution in April last, and is specially fitted for dredging and sounding, still forms the principal sea-going equipment. During the present year the services of a small lugger-rigged fishing boat have also been available. Investigations have been carried on at the Station in the three departments of Zoology, Botany, and Physics.

Up till the end of last June inquiries into the fauna and flora of the Firth of Forth were carried on regularly, by means of dredging and tow-netting and shore-collecting. During the six months following June 1884, Mr. J. R. Henderson, M.B., devoted the greater part of his time and attention to the speciegraphical and faunological work of the Station, and made a specially complete examination of the Crustacea; he obtained and identified fifty species hitherto unrecorded as occurring in the Firth of Forth. A paper on these species was published by him in the 'Proc. Roy. Phys. Soc. Edin.,' 1884–5. Dredging and collecting were continued in the Firth of Forth up till the end of June, and the results are recorded in the note-books of the Station. Mr. Cunningham's time has been much occupied in working at the embryology of teleostean fishes, and in attempts to elucidate the reproduction of Myxine; his work in faunology has been chiefly confined to the Chætopoda. The embryology of some pelagic eggs and that of the herring, together with the habit of the herring in the neighbourhood of the Firth of Forth, were investigated last year. In the first half of the present year a study was made of the development of the cod, haddock, whiting, and gurnard. Since then Myxine has principally received attention.

At the end of June last a summer branch of the Station was established at Millport. The Ark and the yacht were taken thither from Granton, through the Forth and Clyde Canal. The Ark was at first moored in Millport Bay, and afterwards drawn up on shore, and during the months of July and August dredging was carried on in the *Medusa* by Mr. Murray and Mr. J. R. Henderson, and zoological studies were pursued in the Ark by these and several other naturalists. Mr. Henderson was engaged during the whole time in the examination of the Crustacea, Echinodermata, and Polyzoa of the Clyde estuary. Mr. David Robertson, of Glasgow, availed himself of the resources and arrangements provided to pursue his studies of Ostracoda and other minute forms. He is preparing a complete systematic account of the Amphipoda of the Clyde for the Glasgow Natural History Society. The Rev. A. M. Norman spent a fortnight in zoological work at Millport, and Mr. Dendy, of Owens College, Manchester, worked for a time at the physiology of Comatula. At the beginning of September the yacht was brought back to Granton, where she arrived on the 2nd. The Ark has been left at

Millport in charge of Mr. David Robertson, who intends to place in it as complete a collection as he can make of the animals living in the Clyde estuary. The little laboratory will always be open to naturalists who wish to pursue any marine work at Millport.

As soon as the aquarium was in working order some investigations were begun as a preliminary inquiry into the questions concerning oysters in the Firth of Forth. The ultimate object of this work is to institute, if possible, a practicable system of oyster culture by which the beds of the Firth may be replenished. A number of oysters have been obtained from the neighbourhood of Inchkeith, and among these several were ascertained to contain spat in the mantle cavity. Unfortunately the supply of spatting oysters was small, practical experience in the work was wanting at the beginning of the experiments, and the time which could be devoted to the matter was limited. No oysters have been obtained which contained mature spat—that is to say, spat ready to escape from the parent and enter upon the free swimming condition. Consequently the crucial experiments of placing free larvæ, under various conditions, in order to discover a method of obtaining fixed spat with some certainty, have not yet been made; probably no other opportunity will occur until next season. The inquiry into the conditions of oyster culture is somewhat expensive; the oysters themselves cost money, and it is necessary continually to invent and fit up aquaria with different arrangements, in order to test the effect of various conditions. One experiment which ought to be tried next season, and cannot be arranged without considerable expense, is that of keeping some brood oysters and larvæ at a somewhat high temperature, viz., 68° F., which the water in the Firth of Forth scarcely ever reaches. The inquiries carried on in Holland have shown that that temperature is most favourable to the fertility of the parent oyster and the health of the spat. Another experiment which ought to be made is that of enclosing oysters in a marine pond connected with the sea, and endeavouring to collect the spat. The station ought also to have exclusive control over some area of sea bottom suitable for the growth of oysters, in order to try and produce a new and populous oyster bed.

The work of the Station in the Zoological department is only at its beginning. The examination of the data which have been collected with regard to the occurrence of the various species in different parts of the Firth has not yet been made, owing to the pressure of other work. Some progress will be made in this during next winter. Mr. Sloan is devoting much energy to the study of the Cœlenterates, which have been little worked in Britain for some years. The examination of the Chætopods has been already carried out with some completeness. In the new aquarium excellent opportunities are afforded for the study of development. A number of glass vessels have been so arranged that a current of water is continually passing through them, and yet even very small eggs and larvæ cannot escape. This plan has been found the only one reliable for keeping small creatures alive for a long time. However carefully an aerating apparatus is arranged, it is extremely difficult, if not impossible, to prevent the contamination of an isolated quantity of water by the bodies of the specimens that die.

Since the opening of the Station a considerable number of persons have availed themselves of its resources to pursue studies and researches in zoology. In August of the present year Mr. C. F. Marshall, of the

physiological laboratory of Owens College, Manchester, carried out at the Station a series of experiments on the function of the nerve trunks in the lobster, and also studied the histology of muscular tissue in different classes of animals.

During the greater part of August Miss Maconnish, of London, studied in the laboratory. The following is a list of those who have visited the station for the purpose of study and research since its opening:—In 1884, Prof. W. A. Heardman, Univ. Coll., Liverpool, April; Mr. J. R. Davis, Univ. Coll., Aberystwyth, July; Miss Maconnish, London, Aug. and Dec. In 1885, Mr. John Boyd, Manchester, April, few days; Mr. D. M. Stewart, Edinburgh, May 28 to July 28; Dr. Burn Murdoch, Edinburgh, May to July; Dr. J. A. Thomson, M.A., Edinburgh, July 1 to July 28; Dr. Kelso, Edinburgh, July 3 to July 20; Miss Maconnish, London, July 27 to Aug. 25; Mr. J. L. Smith, M.A., Edinburgh, July 30 to Aug. 8; Mr. A. D. Sloan, Edinburgh, Aug. 8 to present time; Mr. C. F. Marshall, B.Sc., Owens Coll., Aug. 17 to Aug. 30.

The following is a list of the papers which have been published by the Zoological department of the Station:—

Critical Note on the Latest Theory in Vertebrate Morphology, 'Proc. Roy. Soc. Edin.,' vol. xii. 1884.

Additions to the Fauna of the Firth of Forth, 'Proc. Roy. Phys. Soc. Edin.,' 1884–85.

Nature of Kupffer's Vesicle (Herring Ovum), 'Proc. Roy. Soc.,' 1884; also in 'Quart. Journ. Mic. Sci.,' Jan. 1885.

Relations of Yolk to Gastrula in Teleostean Ova (Cod, Haddock, Whiting, Gurnard), 'Quart. Journ. Mic. Sci.,' 1885; and 'Proc. Roy. Soc. Edin.,' 1885.

In Botany the flora of the Firth was systematically investigated by Mr. Rattray up till the beginning of June of this year. A collection of the Algæ in the area has been made and systematically arranged. The results of the work were published in several papers on the marine flora of the Firth of Forth, communicated by Mr. Rattray to the Botanical Society and the Royal Society of Edinburgh.

The following is a list of the papers referred to:—

On the Geographical Distribution of Algæ in the Firth of Forth, 'Trans. Bot. Soc. Edin.,' 1884–85.

On the Algæ of Granton Quarry, *ibid.*

The May Island, its Algoid Flora, &c., *ibid.*

On some New Cases of Epiphytism among Algæ, *ibid.*

Observations on the Oil Bodies of the Jungermannieæ, *ibid.*

Note on Ectocarpus, 'Trans. Roy. Soc. Edin.,' Feb. 1885.

Preliminary Note on the Evolution of Oxygen by Algæ, 'Trans. Bot. Soc.,' 1884–85.

The last mentioned paper contained an account of a series of experiments conducted by Mr. Rattray, with a view of discovering and comparing the rate of the production of oxygen by seaweeds of different colours and different species. The oxygen was estimated by means of absorption of the carbonic acid and the oxygen, in a graduated tube over mercury. The gas evolved by the Algæ was collected in large glass tubes full of water, containing the Algæ, and exposed to light.

In the department of Physics and Chemistry the work carried on by Mr. Mill has consisted in the systematic investigation of the temperature and salinity of the water of the Firth of Forth at different seasons and

different places. A new mechanical arrangement for inverting the Negretti & Zambra self-registering thermometer was invented soon after the work was begun; the original arrangement was found to be unsuitable for work on board a small steamer in shallow water where the currents were rapid. In the new frame the inversion is effected by the fall of a messenger along the line upon a horizontal lever. The mechanism was explained by Mr. Mill, in a paper communicated to the Royal Society of Edinburgh in July 1884. For taking samples of water at different depths, a modification of Mr. Buchanan's slip-water bottle is used. The alteration consists in the fact that the slip cylinder, instead of being allowed to run down the line from the hand of the observer, is suspended just above the frame by a spring lock, and is released by the fall of a messenger sent down from the deck of the ship.

In the summer of 1884 an inquiry was made, by means of a number of series of observations at short intervals, into the tidal variation of temperature in the Granton Quarry. The result was communicated to the Royal Society of Edinburgh. The temperature and salinity variations in the Firth were investigated by means of trips on the *Medusa* up and down and across the Firth. The results of the work are published in a paper entitled 'On the Salinity of the Firth of Forth,' 'Proc. Roy. Soc. Edin.,' vol. xiii. On various occasions when the yacht has visited the Clyde observations have been made on the temperature and salinity of that estuary. Some observations have also been made into the physical conditions of the Tay and the Tweed. During the present summer, the months of July and August have been spent by Mr. Mill in similar work at the mouth of the River Spey. A *résumé* of the work which he has so far accomplished in investigating the physical conditions of Scottish estuaries is to be read by Mr. Mill before the present meeting of the Association.

In July of the present year a very thorough investigation was made at the Station, by Mr. H. N. Dickson, of the properties of a number of new thermometer screens invented by Mr. John Aitken, of Darroch. The aim of the inventor was to devise some form of apparatus which should eliminate the causes of error present in the ordinary Stevenson screen, now in general use for meteorological observation. Mr. Dickson gave an account of his researches to the Scottish Meteorological Society, and also to the Royal Society of Edinburgh. Some of the instruments have been taken to the Ben Nevis Observatory, where their investigation is being continued under different conditions.

The Marine Station is one of the regular observing stations of the Scottish Meteorological Society; the ordinary observations on the air and the temperature at the surface and bottom of the quarry are recorded twice daily, and the records forwarded to the society's secretary.

J. T. CUNNINGHAM.

The Committee beg to recommend the renewal of the grant (100*l.*) for the ensuing year.

Report of the Committee, consisting of Sir LYON PLAYFAIR, Professor MOSELEY, Admiral Sir E. OMMANNEY, Mr. P. L. SCLATER, *and* Mr. A. SEDGWICK (*Secretary*), *appointed to prepare a Report on the Aid given by the Dominion Government and the Government of the United States to the encouragement of Fisheries, and to the investigation of the various forms of Marine Life on the coasts and rivers of North America.*

IN Canada there is a *Department of Fisheries*, presided over by the Minister of Marine and Fisheries, to whom a Deputy Minister of Fisheries makes an annual report.

'The duties of the Department of Fisheries consist principally in the administration of all laws relating to the subject of the sea, coast, or inland fisheries; the management, regulation, and protection thereof; and all matters and things relating thereto, or assigned by the Governor in Council to the said department.' [1]

The total expenditure of this department for the year ending June 1884 was $116,531, distributed as follows:—General service, $69,011; fish breeding, $27,585; maintenance of fisheries, protection steamer *La Canadienne*, $19,935.

There are twelve fish-hatcheries in the Dominion, on which the expenditure by the department was in 1884, as stated above, $27,585. Over 53 million fry—chiefly of salmon, trout and white-fish—were turned out from these establishments in 1884.

The United States Fish Commission was instituted in 1871. Its object, as defined by Congress, was as follows:—'To prosecute investigations on the subject of the diminution of valuable fishes, with the view of ascertaining whether any and what diminution of the number of food fishes of the coasts and lakes of the United States has taken place, and if so to what cause the same is due; also, whether any and what protection, prohibitive or precautionary measures in the premises, and to report on the same to Congress.'

To enable it to attain these objects, an appropriation was made to the Commissioner.

In every year since 1871 appropriations have been made by Congress to the Fish Commissioner, to enable him to carry out his recommendations; and the sums voted have increased year by year, until, in 1884, the sum of $245,380 was appropriated.

The following table shows the annual appropriations to the Fish Commissioner since 1871:—1871–72, $9,000; 1872–73, $30,000; 1873–74, $38,500; 1874–75, $23,500; 1875–76, $71,000; 1876–77, $36,045; 1877–8, $75,700; 1878–79, $71,000; 1879–1880, $157,000 (includes $57,500 for steamer *Fish-Hawk*); 1880–81, $121,500; 1881–82, $328,710 45c. (includes $12,709 for *Fish-Hawk* and $145,000 for *Albatross*); 1882–83, $233,319 60c. (includes $45,000 for *Albatross*); 1883–84. $242,500 (includes $10,000 for *Albatross*); 1884–85, $245,380. Total since 1871, $1,683,155 5c.

[1] *Annual Report of the Department of Fisheries of the Dominion of Canada for the year* 1884.

Special appropriations for the International Fishery Exhibition in Berlin, \$20,000 ; ditto in London, \$50,000.

Additional assistance given by Congress and not included in the above sums:—

1. Extensive fish-ponds for breeding by the construction of piers in the sea at Wood Holl, Mass., the headquarters of the Commissioners (in course of construction in 1884) ; estimated cost, \$80,000. Of this sum \$50,000 has already been voted as part of the Harbour Improvement Appropriation.

2. The pay of the officers and men of the United States navy who work the Fish Commission steamers *Albatross* and *Fish-Hawk,* the former being chiefly equipped for ocean, and the latter for coast work. In addition, the navy has general instructions to give such aid as they may be able to the Commission when their ships are in available waters.

3. Printing of the annual report of the Commissioner and of the Bulletin [1] of the United States Fish Commission.

Fish Commission of the various States of the Union.

In addition to the assistance given by the Federal Government 'to the encouragement of fisheries, and to the investigation of the various forms of marine life on the coast and rivers of North America,' thirty-one States had in 1882 their own Fish Commissions, subsidised in each case by annual appropriations from the State Government.

The total sum appropriated in this manner in the year 1882 was \$120,948, and the total amount appropriated since the institution of the State Fish Commissions was, in 1882, \$1,101,096.

Report of the Committee, consisting of Professor HUXLEY, Mr. SCLATER, Mr. HOWARD SAUNDERS, Mr. THISELTON DYER, *and* Professor MOSELEY (*Secretary*), *appointed for the purpose of promoting the establishment of Marine Biological Stations on the coast of the United Kingdom.*

THE Committee beg leave to report that they have received the sum granted (150*l.*) from the Treasurer of the Association, and have paid it to the funds of the Marine Biological Association of the United Kingdom, as the most direct means of promoting the speedy establishment of a marine laboratory in a most favourable situation on the British coast—namely, Plymouth. An excellent site for a laboratory has been granted to the Marine Biological Association by Government, at Plymouth. A sum of 8,000*l.* has been raised by subscriptions and donations, the Government has promised to aid the working of the laboratory by an annual subsidy, and there is every prospect of success. It is probable that the building of the laboratory will commence in November.

[1] 'Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, that the public printer be and he hereby is instructed to print and stereotype, from time to time, any matter furnished him by the United States Commissioner of Fish and Fisheries relative to new observation, discoveries, and applications connected with fish culture and the fisheries, to be capable of being distributed in parts, and the whole to form an annual volume or bulletin not exceeding 500 pages. The extra edition of said work shall consist of 5,000 copies, of which 2,500 shall be for the use of the House of Representatives, 1,000 for the use of the Senate, and 1,500 for the use of the Commissioner of Fish and Fisheries.'

Report of the Committee, consisting of Dr. H. C. Sorby *and* Mr. G. R. Vine, *appointed for the purpose of reporting on recent Polyzoa. Drawn up by* Mr. G. R. Vine.

Report on Recent Marine Polyzoa; Cheilostomata and Cyclostomata only.

Part I. Introduction.

In the present Report I have been compelled to adopt a classification somewhat different from that which I followed in my Fifth Report on Fossil Polyzoa (1884). Since the first publication of the Report, Mr. George Busk's long-expected *Challenger* monograph (Cheilostomata) has appeared, and as his scheme of classification differs from that of Mr. Hincks, both in the 'British Marine Polyzoa,' and also in the 'Contributions towards a General History of the Marine Polyzoa,' I have thought it best to allow each author to speak for himself, rather than to try to harmonise or alter the text, except by the scheme adopted farther on.

In his Introduction to the *Challenger* Report, Mr. Busk remarks, 'that although many of the family groups may in some measure be regarded as expressing natural alliances,' others can only be considered as artificial, 'especially in the sub-division C, or Escharina . . . . and as such they must perhaps remain until we are better acquainted with the true significance of the minute parts or organs upon which the distinctive characters are in many cases founded . . . . Nevertheless, in order to place myself as far as possible in accord with modern views, I have, in the heterogeneous Family Escharidæ more especially, adopted partially the nomenclature proposed by Mr. Hincks and Professor Smitt; but in doing this I have found it impossible to avoid a certain amount of the confusion necessarily incidental to an attempt to graft a new system upon an old one based on a different set of characters.'

It will be remembered that in the arrangement of his families and genera in the 'British Marine Polyzoa,' and in his subsequent papers in the 'Annals and Magazine of Natural History,' Mr. Hincks sets a very high value on zoœcial characters. Mr. Busk also, in the *Challenger* Report, appreciates to a large extent this method in dealing with special groups; at the same time he says we are not 'in a position fully to appreciate the relative value of the *zoœcial* as compared with the *zoarial* characters . . . the individuality of the zoarium as a continuous whole or entity having been too much overlooked in the almost exclusive consideration of its component parts or segments.'

In the following 'Scheme of Classification' all the family names and divisions are the same as those used by Mr. Busk, with the exception of Family VII. *Notamiidæ*, which was founded by Mr. Hincks for the placement of a very peculiar polyzoon. There are also parts of the families Porinidæ and Myriozoidæ still unaccounted for in the arrangement adopted. These I treat of separately, out of deference to Mr. Hincks and others who have followed his arrangement, formulated for his work on British Marine Polyzoa.

Before passing on to the Classificatory List, it will be better, I think, to give a brief digest of the terms used by Mr. Hincks and by Mr. Busk, in the prefaces to their systematic arrangements both in the British Marine Polyzoa and in the *Challenger* Report. For obvious reasons I do not specially commit myself to remarks on the systematic arrangements of authors previous to the issue of these two works. In my former reports on Fossil Polyzoa I have pointed out the varied lines of investigation followed by other authors in their methodical classifications, but these are most noticeable in the arrangements of Reuss and Manzoni on the fossil species, and by Professor Smitt in his various works on Recent Polyzoa, full digests of which were given in my fifth report.

TERMINOLOGY, according to the Rev. Thomas Hincks and Mr. George Busk.

ZOŒCIUM.—(=*Cell. Cystid.* Nitsche: *Brutkapsel*, Reichert). The chamber of the polypide.

ZOARIUM.—(=*polyzoarium* auctt.). The composite structure formed by repeated gemmation.

OŒCIUM.—(=*ovicell* auctt.)—The special receptacle attached to the zoœcium, in which the ova complete their development into the larva.—*Cheilostomata.*

GONŒCIUM.—A modified zoœcium set apart for reproductive functions. *Cyclostomata.*

GONOCYST.—The inflation of the surface of the zoarium, in which the embryos are developed.

Mr. Hincks (Introduction, p. iii, note), speaks of the ovicell as a 'marsupium,' and he restricts the use of the term *Oœcium* for *Cheilostomatous* Polyzoa. The modified reproductive cell of *Crisia* and the superficial inflation of the zoarium of many of the *Cyclostomata*, being different structures, should be distinguished by separate names.

Mr. Busk, in his *Challenger* Monograph (pp. xvi to xviii), employs certain terms in a particular sense.

I. ZOARIUM dimorphous: that is, erect or free: decurrent and encrusting, and more or less closely attached.

II. ZOŒCIA, surface—

1. Smooth.
2. Polished.
3. Granular.
4. Verrucose.
5. Rugose.
6. Pitted.
7. Punctulate, minutely porous.
8. Punctate, with larger perforations.
9. Reticulate.

Orifice,

1. Orbicular.
2. Elliptical.
3. Semi-orbicular.
4. Crescentic.
5. Coarctate.
6. Trifoliate.
7. Clithridate.

The lower border may be—

1. Entire, sinuous or straight.
2. Mucronate.
3. Emarginate.
4. Dentate.
5. Bi-dentate.
6. Incised.

The peristome may be—

1. Thin or thick.
2. Elevated, produced, or bevel.
3. Armed with oral spines, either rigid or articulated.
4. Unarmed.

The other divisions of this part of Mr. Busk's work refer to :—

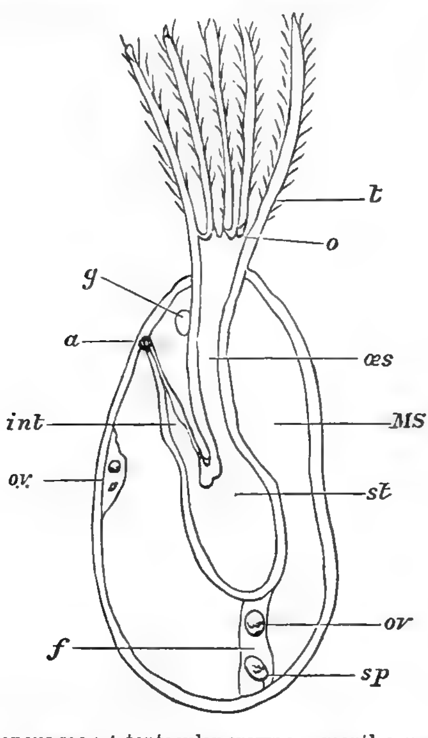
III. Special pores on the front of the zoœcia.
IV. The Oœcia.
V. Special organs : *a. Avicularia,*
§ as to function. | §§ as to position.
b. Vibracula : *a.* simple, *b.* compound.
VI. Chitinous elements.

Opesia, *Dr. Jullien.* Certain of the Membraniporæ having a thick calcareous expansion were covered when living by a membrane, in which was the opercular opening. This is the 'opesia' or opesial opening of Dr. Jullien.

Aperture—restricted for the proper opening.

General Plan of Structure.

'In every polyzoon,' says Mr. Hincks, 'we distinguish two fundamental elements, the zoœcium and the polypide. These are the primary



MS, membranous sac ; *t*, tentacular crown ; *o*, mouth ; *œs*, œsophagus ; *st*, stomach ; *a*, anus ; *int*, intestines ; *g*, ganglion ; *f*, funiculus ; *ov*, ovary ; *sp*, spermary. (After Hincks).

zooids in every colony. When the larva fixes itself, after its brief term of free life, it is metamorphosed into a single sac or cell, enclosing a mass

of formative material and certain rudimentary elements, out of which a polypide is developed. These two constitute together the primary term (Hks.) [germ ?],[1] of a colony; and by repeated buddings, according to the pattern of the species, the composite zoarium is built up. The colony is formed by the indefinite repetition of the primitive zooids and their modifications.'—Brit. Mar. Poly. p. iv.

I. Zoœcium.

In dealing with the zoœcium in the various aspects which it presents to the student in its dried condition it may be well to mention one or two particulars before passing on to special details. In studying the Fossil, in connection with the Recent Polyzoa, great caution is necessary in making observations on abnormal forms. In the living state we have more than one character to guide us in our deliberations; but in the dried state, or in the fossil, very often large portions of the outer crust are so calcified that sometimes only the mouth of the cell is visible; possibly oœcia or avicularia, hence the necessity of some such plan of classification as that afforded by Mr. Hincks, based on persistent characters. Mr. Waters, in following Mr. Hincks, when studying the Australian fossil Bryozoa, had occasionally the merest fragment of a colony to deal with; and had it not been for certain facts on which he could rely with safety, his task must have been almost a hopeless one. These remarks, however, apply more particularly to Cheilostomatous groups, such as the MEMBRANIPORIDÆ and the ESCHARIDÆ of Busk, together with some allied genera which will be specially referred to.

In many cases the primary cells in colonies of the MEMBRANIPORIDÆ are peculiarly shaped. For the most part they are somewhat rounded, with a large terminal aperture closed in by a membrane and usually surrounded by a number of spines. Van Beneden described such a form by a distinct generic term, that of *Tata*, and in connection with the study of fossil Colonial growths the *Tata* stages of the zoarium are very interesting. Mr. Waters met with some peculiarities in the Australian Bryozoa, and I have met with a few examples in the Cretaceous—Eocene —Miocene, Crag and Post-pliocene *Membranipora* of Mr. Hincks. This group, however, is broken up by Mr. Busk in his *Challenger* Report, and particulars of the genera, and the characters upon which these are founded, are given in the body of the present report.

In the zoœcia of *Megapora* there is a depressed area surrounded by a raised margin, and partially closed in by a calcareous lamina. The aperture is trifoliate, the upper portion surrounded by spines, similar in some respects to *Cribrilina radiata* and *Microporella ciliata*. The depressed area with the raised margin separates the genus from the other genera in this respect, but there are some points of resemblance between *Megapora ringens*, and the *Membranipora Flemingii* of authors, and the species Mr. Hincks thinks ought to be included in the genus Megapora. This latter species has also a trifoliate orifice, but the spines of the fully developed cell are very different—so also are several other features—of the matured and immature cell.

In the *Challenger* Report Mr. Busk makes the *Membranipora Flemingii*

[1] 'Term' is used by Hincks, but this may be a misprint for the bracketed word [germ ?].

of Hincks, and others, the type of his genus *Amphiblestrum* Gray, and he places in the group six species, four of which are described and figured in the report, the other two referred to and redescribed. The trifoliate character of the orifice is not found in the whole of Mr. Busk's species; some orifices are obovate, but all have a partially internal calcareous lamina. So that in dealing with the two groups—*Megapora* and *Amphiblestrum*—we shall have to deal with other characters besides that of the trifoliate orifice. In all probability the one or the other peculiarities of the group date back to the Upper Chalk, but in a very modified form as regards species.

In the MICROPORIDÆ the front wall of the zoœcia is wholly calcareous, but the margins are elevated and there is a slight tendency to trifoliation in *M. complanata*, but there are no marginal spines. In his papers on Australian Bryozoa Mr. Waters places two or three forms in this genus, and he alludes to one form as *M. hippocrepus*, Goldf. None of the species, however, are to be compared with the semitrifoliate orifice of *M. complanata*, Norman=*Membranipora Smitti*, Manzoni. We thus carry back the partially trifoliate orifice to the Italian Pliocene, but we also find it, together with other characters, in *Membranipora trifolium* in the Crag.

In *Steganoporella* there is in the orifices of some of the cells a slight tendency to trifoliation; but there are other marked characters which separate the species from *Micropora*, although the external aspect of forms of the two genera are similar. Only one species is described by Mr. Hincks, *S. Smittii*, but in describing *S. magnilabris*, Busk, *Chal.* Rep., Mr. Busk re-defines and limits the genus and species. 'The chief character on which the genus *Steganoporella*, Hincks, ... is based is the bithalamic condition of the zoœcium. Some way below the upper extremity of the cell a diaphragm shuts off the lower portion of the cavity, and forms a distinct chamber for the polypide. A tubular passage extends upwards from this chamber, and opens . . . . into the upper chamber, which is always large, and in certain cells of very ample dimensions . . . . The opening of this chamber is closed by a very large operculum . . . . which also protects the entrance to the tubular passage through which the polypide issues.' (Hincks' 'Annals,' Feb. 1882, p. 83.) 'Smitt places *Steganoporella* amongst the Microporidæ . . . . but I am now inclined to agree with Dr. J. Jullien so far as to regard the dithalamic condition of the zoœcium, which distinguishes it, as entitling it to rank in a separate *family* group'—Fam. Steganoporellidæ, Hincks. (Annals, May, 1884, p. 358.) I have preferred to give, on this point especially, both the first-formed and matured expressions of the author.

Another very important group which seems to be far more natural that the last is the MYRIZOIDÆ, Smith and Hincks. It contains the genera *Schizoporella*, and *Mastigophora*, of Hincks, and its distinguishing feature is the sinus on the lower margin of the orifice. The sinus is also found in species of *Hippothoa* which Mr. Hincks places in the family, but notwithstanding this Mr. Busk (*Chal. Rep.*) removes it and places it with his stoloniferous group, particulars of which are given in the body of the present report. But as in other groups, so in this, dependence in the divisions must not be placed upon one character alone; other characters must be considered as well as this, and the systemist would do well to look all around his species before deciding to which group it belongs. The sinus of *Schizoporella spinifera* is very much like the sinus of *Smittia marmorea*; so also is the orifice, excepting the spines in the former species.

But the remarkable development of other characters in *Smittia*, *Schizoporella*, and *Mastigophora Hyndmanni* increases the interest in the study of the zoœcium having a sinuated lip. The group, however, has had a wonderful history, for it reaches back to the Cretaceous epoch, and many and diverse are the fossil forms of the older authors which are now regarded as synonyms of well-defined recent species. Taking only one, *Schizoporella unicornis*, Johnson, no fewer that nine species—or even more if we include the varieties, some of which are fossil forms—are placed as synonyms. In his papers on the Australian Bryozoa, Mr. Waters describes a number of species belonging to the genus *Schizoporella*, and Mr. Busk adds additional particulars in his *Challenger* Report.

Species belonging to the MICROPORELLIDÆ of Hincks demand a closer and more critical study than they have yet received. Not so much on account of the orifice—which is more or less semicircular with margin entire, but on account of the semilunate, or circular, pore on the front wall. There is connected with this pore a physiological mystery, and there seems to be as yet no possibility of its solution. One species that I have just described in the Jesson collection (Cambridge Greensand) [1] seems to be related to the group, but we have forms in the Carboniferous rock which apparently belongs to this, or some allied group not represented in the Mesozoic rocks. These, however, we place at present with the Cyclostomata.

In the closer study of species which possess this pore below the orifice Mr. Busk has felt himself compelled to establish two families—the ONCHOPORIDÆ and ADEONEÆ—for two different groups in which this peculiar feature is present. In remarking on Onchoporidæ (*Chal. Rep.* p. 102), Mr. Busk says: 'Considering, as Mr. Hincks remarks truly, that we do not know the physiological import of the lunate pore, and that the form of the mouth (in *Microporella*) is common to a vast number of species, I am not at present inclined to agree with him in regarding these two characters, even in combination, as alone sufficient to justify the association of such otherwise very dissimilar forms as *Onchopora Sinclairii* and *Onchoporella bombycina*, Busk, &c., with the Lepralian Microporellidæ.' And again, in his elaborate introductory remarks on the family Adeoneæ (*Chal. Rep.* p. 178): 'The presence of a median pore or its equivalent, which though not formed in the same way in all the Adeoneæ, doubtless subserves the same function in all, and in every case appears to me to differ widely in nature from the lunate pore in *Onchopora*, *Microporella*, &c., as well as from the tubular pores of *Tessarodoma*, *Tubucellaria*, &c.' I had prepared several original remarks on these pores which I had made in a study of the *Microporella*, *Onchopora*, and *Adeonea* in my cabinet; but I thought that the authority of Mr. Hincks, Mr. Waters, and also of Mr. Busk on the same subject would appear with much better grace in this introductory part. Nevertheless I should strongly direct the attention of students to this subject, especially upon species from new localities.

In his remarks on a specimen of *Microporella fuegensis*, Busk (Burmese coast), Mr. Hincks says that 'the sub-oral pore presents some peculiarities. It is placed *immediately* below the rim of the orifice in front, and is only found in the adult cell. In the marginal zoœcia the orifice is sub-orbicular and the peristome not elevated; but in a more

[1] *Abstracts in Proceedings of the Geo. Soc. of London*, No. 470, p. 74.

advanced stage the peristome rises considerably round the back and sides of the orifice, but not in front, the result being that a sinus is formed here. In a still more advanced stage the *margin* of the side wall of the peristome is extended across the upper part of this sinus, forming a narrow rim, and converting the open fissure into a circular pore, which communicates directly with the interior of the tubular peristome.'—*Annals*, May 1884, p. 360.

The zoœcia of the CRIBRILINIDÆ appear to me to afford a good basis for a natural group, though the area of the cell varies very much in the different species. The zoœcial features, however, are very peculiar, and the forms that are grouped together in the family are beautiful in the extreme. In many—both fossil and recent—the whole front of the cell below the orifice is either fissured, or marked by rows of punctures without fissures. Both the *Cribrilinæ* and the *Membraniporella* are widely distributed in the present seas; but only the first of these genera are found, so far as is known to me up to date, fossil, and very full particulars of the species are given in my Fifth Report on Fossil Polyzoa.

Much might be said about the zoœcia having the mucronate character in the lower lip of the orifice of Mucronella (Hincks), only that I have referred to several remarkable features in the species found in the *Challenger* dredgings.

For his own justification in the plan of classification adopted by Mr. Hincks in his 'British Marine Polyzoa,' the author says, in his preliminary essay[1] on the subject: 'The essential structure of the individual cell must certainly be accounted the most important point, both in itself and as a clue to relationship. . . . Unless we are content with the old (and certainly very simple) method of lumping all erect forms together, without any reference whatever to the cell, we have only a choice between these two courses: to found genera for the variations of growth, as well as for the more important modifications of the cell in each family; *or to make the zoœcium the basis of the genus, and treat the ordinary variations of habit sub-sectionally.* I was at one time inclined to the former method;[2] but further experience of the practical work of classifying the Polyzoa has brought me to a much greater extent into sympathy with Professor Smitt's views.' Much, however, remains to be done before our groups will be wholly satisfactory, as will be seen when the student takes up the study of the different families, genera, and species enumerated in the present report.

There are in the zoœcium several structural characters, such as communication-pores—avicularia—avicularian chambers, &c. These ought to be specially studied, and seeing what admirable work has been done in this direction by Mr. Waters and Mr. Busk, I can only say that, with all our knowledge, much remains to be done.

A very special study has been given to the zoœcium of Catenicella by Mr. Waters (Quart. Journ. Geo. Soc. vol. xxxix. pp. 423–429) some particulars of which are given in the text of the present report, but for fuller details, attention is directed to the paper itself, especially so as in the same paper Mr. Waters (p. 425) gives some account—all too briefly, though—of his views on the function of the avicularia. He also refers to the classification of the Membraniporæ proposed by Dr. Jules Jullien.

[1] *Ann. Mag. Nat. Hist. Ser.* 5, vol. ii. 1879, p. 160.
[2] *Ibid.* Dec. 1877, p. 523.

As to the zoœcia of the Cyclostomata it is not necessary to make any lengthy remarks here. In treating of this division of my subject, I have given very full particulars in my fourth and fifth reports, and I must refer the student to these for special details, and in that division of my subject in the present report—Cyclostomatous Polyzoa—I have given additional particulars. These for the present must suffice, until I have completed certain investigations into the structural peculiarities of the zoœcia in Palæozoic Polyzoa. There are, however, certain peculiarities connected with the study of the Ctenostomatous cell and its stoloniferous processes that may merit some consideration at least. But these details have been so ably worked out by Mr. Hincks in his 'History of British Marine Polyzoa,' especially in the description of species, that I refer the student without the least hesitation to the work itself, especially so as I am not able to touch upon the Ctenostomata in this report.

II. Zoarium.

I cannot blame Mr. Hincks for his adoption of zoœcial, in preference to zoarial, characters, as a basis of generic distinction. Still at the same time, as Mr. Busk asserts in the passage already quoted from the *Challenger* Report, 'it would be wise to take, at times, into consideration some of the zoarial features, modes of growth, and peculiarities of development in the zoarium, not as a basis of classification, but as a means of arriving at some conclusion that would help us to understand the close, or remote, relationship of the Palæozoic with Recent Polyzoa.' This study, however, must be carried out with Cyclostomatous rather than with Cheilostomatous groups, for I know of no form of polyzoa in the older rocks that would afford us true links of relationship with the latter recent group, or even with the modified zoarial Cheilostomatous structures of the Mesozoic age. Well-developed Cheilostomata are abundant in the Cretaceous rocks, both of this and other countries, and the peculiarities of growth may have been, at times, too much relied upon by authors. On this point I cannot help quoting a passage from the first of the series of papers on Australian Bryozoa by Mr. Waters.

'Probably no naturalist at all thoroughly acquainted with the Bryozoa will again attempt to sustain such genera as the old *Lepralia* and *Eschara*; but it may be well to examine carefully the growth of the Bryozoa before we entirely reject the form of the colony as of classificatory value; for in many cases it may be shown in this way from which part of a zoœcium the following zoœcium grows. The mode of growth of *Lepralia* and *Eschara* indicate no structural difference, for the young zoœcia in both grew out from the same part of the parent cells, and *Eschara* was only formed of *Lepralia* cells, back to back, often very slightly attached. . . . The form of the aperture must be the first consideration; but especially among fossils we must carefully notice how they grow.' (Quart. Jour. Geo. Soc., vol. xxxvii. p. 311).

III. The Polypide.

Of the Polypide it seems to be almost folly to speak in a report like the present one, as I have had to deal more particularly with the homes of the animal, rather than with the animal itself. Still at the same time I cannot allow the report to pass from my hands without making some reference to the polypide, for no very clear idea of the beauty of the zoœcia

can be obtained without we make a partial study as to how the cell is built up by the polypide. For the purpose of this study I know of no better training than the mastery of the details furnished by Barrois on Embryology, both of Cheilostomatous and Cyclostomatous Polyzoa, and after this the study of mounted or living specimens of *Carbasea* for the Cheilostomata, *Zoobotryon pellucidus*, Ehrenb., for the Ctenostomatous, and *Crisia* or *Hornera* (*Retihornera*, Busk) *foliacea*, Macgil., for the Cyclostomatous groups. In the first and second the endosarc and growth and development of the cells may be conveniently studied, and according to the character of the specimens, the growth and development of the polypide, and in the latter group the periodical growth of the cell and of the intercellular tubes, as noted by Busk ('Crag Polyzoa') and by Mr. Waters ('Australian Bryozoa: Cyclostomata,' Quart. Jour. Geo. Soc., vol. xl. p. 675 &c.)

Classification of Marine Polyzoa. Busk *and* Hincks (part).

Sub-order. **CHEILOSTOMATA**, *Busk.*

Division I. STOLONATA, *Carus.*

Family I. **Æteidæ.**

Genus 1. Ætea.

Family II. **Eucratiidæ.**

Genus 2. Eucratea.
„ 3. Hippothoa.
Genus 4. Pasythea.
„ 5. Brettia.[1]

Family III. **Chlidoniadæ.**

Genus 6. Chlidonia.

Division II. RADICELLATA.

Group A. Cellularina.

Family IV. **Catenariadæ.**

Genus 7. Catenicella.
Genus 8. Catenaria.

Family V. **Cellulariidæ.**

Genus 9. Cellularia.
„ 10. Menipea.
„ 11. Emma.
„ 12. Scrupocellaria.
Genus 13. Canda.
„ 14. Nellia.
„ 15. Caberea.

Family VI. **Bicellariidæ.**

Genus 16. Bicellaria.
„ 17. Bugula.
„ 18. Kinetoskias.
Genus 19. Ichthyaria.
„ 20. Beania.

[1] See Busk, *Challenger Report*, p. xxii. See also genus 26, and p. 46, *ibid.*

Family VII. **Notamiidæ** (*Hincks*, not *Busk*).

Genus 21. Notamia.

Family VIII. **Gemellariadæ.**

Genus 22. Gemellaria.
,, 23. Didymia.
,, 24. Dimetopia.
Genus 25. Scruparia.
,, 26. Brettia.[1]
,, 27. Huxleya.

Family IX. **Farciminariadæ.**

Genus 28. Farciminaria.

Group B. FLUSTRINA.

Family X. **Flustridæ.**

Genus 29. Flustra.
,, 30. Carbasea.
Genus 31. Diachoris.

Family XI. **Membraniporidæ.**

Genus 32. Membranipora.
,, 33. Amphiblestrum.
,, 34. Biflustra.
Genus 35. Foveolaria.
,, 36. Pyripora.
,, 37 (?). Megapora[2] (*Hincks*)

Family XII. **Microporidæ.**

Genus 38. Micropora.
,, 39. Vincularia.
,, 40. Steganoporella.
Genus 41. Caleschara.
,, 42. Diplopora.
,, 43. Setosella.

Family XIII. **Electrinidæ.**

Genus 44. Electra.

Group C. ESCHARINA.

Family XIV. **Bifaxariadæ.**

Genus 45. Bifaxaria.
Genus 46. Calymmophora.

Family XV. **Salicornariadæ.**

Genus 47. Salicornaria.
Genus 48. Melicerita.

Family XVI. **Tubucellariadæ.**
(= Porinidæ, *Hincks*).

Genus 49. Tubucellaria.
Genus 50. Siphonicytara.

(?) Family XVI*a*.[3] **Porinidæ**, *Hincks*.

Genus 51 (?). Lagenipora.
Genus 52 (?). Celleporella.

(?) Family XVI*b*.[3] **Myriozoidæ**, *Hincks*.

Genus 53 (?) Rhynchopora, *H.*
Genus 54 (?) Schizotheca, *H.*

[1] See note, genus 5, *ante*.
[2] Not accounted for in the classification of Mr. Busk.
[3] *Ibid.*

Family XVII. **Onchoporidæ.**

Genus 55. Onchopora. Genus 56. Onchoporella.

Family XVIII. **Reteporidæ.**

Genus 57. Retepora.
„ 58. Reteporella.
Genus 59. Turritigera.

Family XIX. **Cribrilinidæ.**

Genus 60. Cribrilina. Genus 61. Membraniporella.

Family XX. **Microporellidæ.**

Genus 62. Flustramorpha. Genus 63. Microporella.

[Family XX*a*. Not accounted for by Mr. Busk.
Genus (?) Diporula, *Hincks*. Genus (?) Monoporella, *Hincks*.]

Family XXI. **Escharidæ.**

Genus 64. Eschara.
„ 65. Lepralia.
„ 66. Chorizopora.
„ 67. Porella.
„ 68. Escharoides.
„ 69. Smittia.
„ 70. Micronella.
„ 71. Aspidostoma.
„ 72. Schizoporella.
Genus 73. Gephyrophora.
„ 74. Myrizoum.
„ 75. Haswellia.
„ 76. Tessaradoma.
„ 77. Gemellipora.
„ 78 (?). Umbonula,[1] *Hincks*.
„ 78 (?). Phylactella,[1] *Hincks* (pt).
„ 79 (?). Palmicellaria,[1] *Hincks*.

Family XXII. **Adeoneæ.**

Genus 80. Adeona.
„ 81. Adeonella.
Genus 82. Reptadeonella.

Family XXIII. **Celleporidæ.**

Genus 83. Cellepora, *Fabricius*.

Family XXIV. **Selenariadæ.**

Genus 84. Cupularia. Genus 85. Lunularia.

It appears to me very improbable that Mr. Hincks will prefer the classification of Mr. Busk for that of his own. In his published papers, since the issue of the 'Challenger' Report, Mr. Hincks takes his own course, and it would be impertinent on my part to interfere with his arrangement. The numbered consecutive families and genera are those of the 'British Marine Polyzoa'; the interpolated families and genera (unnumbered) are the additions Mr. Hincks has been compelled to adopt in his study of the many foreign groups placed in his hands by collectors and others.

Sub-order. **CHEILOSTOMATA**, *Busk*.

Family I. **Æteidæ**, *Hincks*.

Genus I. Ætea, *Lamouroux* (1).

[1] Only partly accounted for in the classification of Mr. Busk

Family II. **Eucratiidæ**, *Hincks.*

Genus 2. Eucratea, *Lamx.*
„ 3. Gemellana, *Savig.*
„ 4. Scruparia, *Hincks.*
Genus 5. Huxleya, *Dyster* (27).
„ 6. Brettia, *Dyster* (5 & 26).
Genus. Rhabdozoum, *Hincks.*

Family III. **Cellulariidæ**, *Hincks.*

Genus 7. Cellularia, *Pallas* (9).
„ 8. Menipea, *Lamx.* (10).
Genus 9. Scrupocellaria, *Van Ben.* (12).
„ 10. Caberea, *Lamx.* (15).

Family IV. **Bicellariidæ**, *Hincks.*

Genus 11. Bicellaria, *Blainv.* (16).
„ 12. Bagula, *Oken* (17).
Genus 13. Beania, *Johnst.* (20).
Genus. Stiparia, *Hincks.*
Genus. Stolonella, *Hincks.*

Family V. **Notamiidæ**, *Hincks.*

Genus 14. Notamia, *Fleming* (?).

Family VI. **Cellariidæ**, *Hincks.*

Genus 15. Cellaria (pt.) *Lamx.* (47).
Genus. Farcimia, *Pourtales.*

Family VII. **Flustridæ**, *Hincks.*

Genus 16. Flustra, *Linn.* (29).

Family VIII. **Membraniporidæ.**

Genus 17. Membranipora, *Blainv.* (32).
„ 18. Megapora, *Hincks* (37 ?).
Genus. Euthyris, *Hincks.*
Genus. Siphonella, *Hincks.*

Family IX. **Microporidæ**, *Hincks.*

Genus 19. Micropora, *Gray* (38).
„ 20. Steganoporella, *Smitt* (40).
Genus 21. Setosella, *Hincks* (43).

Family. **Steganoporellidæ**, *Hincks.*

Genus. Steganoporella, *Smitt.*
Genus. Smittipora, *J. Jullian.*

Family X. **Cribrilinidæ**, *Hincks.*

Genus 22. Cribrilina, *Gray* (60).
„ 23. Membraniporella, *Smitt* (pt.) (61).

Family XI. **Microporellidæ**, *Hincks.*

Genus 24. Microporella *Hincks* (63).
„ 25. Diporula, *Hincks* (?).
Genus. 26. Chorizopora, *Hincks* (66).

Family. **Monoporellidæ**, *Hincks.*

Genus. Monoporella, *Hincks.*

? Family. **Cyclicoporidæ**, *Hincks*.

Genus. Cyclicopora, *Hincks*.

Family XII. **Porinidæ**, *Hincks*.

Genus 27. Porina, *D'Orb.* (?).
„ 28. Anarthropora *Smitt* (pt.) (?).
Genus 29. Lagenipora, *Hincks* (51 ?).
„ 30. Celleporella, *Gray* (52 ?).

Family XIII. **Myriozoidæ**, *Hincks*.

Genus 31. Schizoporella, *Hincks* (72).
„ 32. Mastigophora, *Hnks.* (?).
Genus 33. Rhynchopora, *Hincks* (53 ?).
„ 34. Schizotheca, *Hincks* (54 ?).
„ 35. Hippothoa, *Lamx.* (3).

Family XIV. **Escharidæ**, *Hincks*.

Genus 36. Lepralia (pt.) *Johnst.* (65).
„ 37. Umbonula, *Hincks* (78 ?)
„ 38. Porella, *Gray* (67)
„ 39. Escharoides, *Smitt* (69).
Genus 40. Smittia, *Hincks* (69).
„ 41. Phylactella, *Hincks* (78?).
„ 42. Mucronella, *Hincks* (70).
„ 43. Palmicellaria, *Alder* (79?).
„ 44. Retepora, *Imper.* (57).
Genus. Aspidostoma, *Hincks* (71).

Family XV. **Celleporidæ**, *Hincks*.

Genus 45. Cellepora, *Fabric.* (83).

Family. **Selenariadæ**, *Busk*.

Genus. Cupularia, *Lamx.* (84). Genus. Lunulites, *Lamx.* (85).

The numbers on the right hand side of the above list refer to the arrangement in the body of the present Report.

Alphabetical List of Families, Genera, and Species (not synonyms) referred to in the present Report.

A.

Adeona, *Lamouroux* (Genus 80).
arborescens, *Kirchenpauer*.
albida, *Kirchen.*
appendiculata (MS.), *Busk.*
cellulosa, *Macgil.*
foliacea, *Lamx.*
Gattyæ, *Busk.*
grisea, *Lamx.*
intermedia, *Kirchen.*
lancifera (MS.), *Busk.*
lycopodioides (MS.), *Busk.*
macrothyris, *Kirchen.*
microthyris (MS.), *Busk.*
vulga (MS.), *Busk.*
Wilsoni, *Macgil.*
Adeoneæ, *Busk* (Family XXII.).

Adeonella, *Busk* (Genus 81).
arcuata (MS.), *Busk.*
atlantica, *Busk.*
crassa (MS.), *Busk.*
dispar, *Macgil.*
distoma, *Busk.*
var. imperforata, *Busk.*
dolichostoma (MS.), *Busk.*
falciformis (MS.), *Busk.*
feugensis, *Busk.*
fissa, *Hincks.*
Heleri (MS.), *Busk.*
intricaria, *Busk.*
lichenoides, *Milne Edw.*
megapora (MS.), *Busk.*
mucronata, *Macgil.*

Cellepora
Simonensis, *Busk.*
solida, *Busk.*
tridenticulata, *Busk.*
tuberculata, *Busk.*
tubigera, *Busk.*
tubulosa, *Hincks.*
vagans, *Busk.*
Celleporella, *Hincks* (Genus 52 ?).
lepralioides, *Norman.*
pygmea, *Norman.*
Celleporidæ, *Busk & Hincks* (Family XXIII.).
Cellularia, *Pallas* (Genus 9).
biloba, *Busk.*
cirrata, *Busk.*
crateriformis, *Busk.*
cuspidata, *Busk.*
elongata, *Busk.*
Peachii, *Busk.*
quadrata, *Busk.*
Cellulariadæ, *Busk* (Family V.).
Chlidonia, *Savigny* (Genus 6).
Cordiera, *Aud.*
Chlidoniadæ, *Busk* (Family III.).
Chorizopora, *Hincks* (Genus 66).
Brongniartii, *Aud.*
Honolulensis, *Busk.*
hyalina.
var. Bougainville, *Busk.*
Cribrilina, *Gray* (Genus 60).
annulata, *Fabric.*
cribrosa, *Heller.*
ferox, *Macgil.*
figularis, *Johnst.*
var. α. fissa.
floridiana, *Smitt.*
furcata, *Hincks.*
Gattyæ, *Busk.*
var. α.
hippocrepis, *Hincks.*
Jaubertii, *Aud.*
labiosa, *Busk.*
var. α. fragilis, *Busk.*
latimarginata, *Busk.*
monoceros, *Busk.*
philomela, *Busk.*
var. α. adnata, *Busk.*
punctata, *Hassall.*
var. α. *Hincks.*
monoceros (?), *Macgil.*

Cribrilina
radiata, *Moll.*
var. α. *Hincks.*
,, β. *Hincks.*
,, γ. tenuirostris, *Hks.*
speciosa, *Hincks.*
tubulifera, *Hincks.*
Cribrilinidæ (Family XIX.).
Crisia, *Lamx.* (Cyclostomata, Genus I.).
acropora, *Busk.*
attenuata, *Heller.*
biceliata, *Macgil.*
Californica, *D'Orb.*
conferta, *Busk.*
cornuta, *Linn.*
var. geniculata, *Busk.*
denticulata, *Lamx.*
eburnia, *Linn.*
var. α. aculeata, *Hassall.*
,, β. producta, *Smitt.*
eburneo-denticulata, *Smitt.*
Edwardsiana, *D'Orb.*
elongata, *Milne-Edw.*
var. angustata, *Waters.*
fistulosa, *Heller* } distinct
fistulosa, *Busk* } forms (?).
Holdsworthii, *Busk.*
margaritacea, *Busk.*
Martinicensis, *D'Orb.*
Patagonica, *D'Orb.*
producta, *Smitt.*
punctata, *D'Orb.*
recurva, *Heller.*
setosa, *Macgil.*
sertutaroides, *D'Orb.*
Sinclarensis, *Busk.*
sinensis, *D'Orb.*
tenuis, *Macgil.*
Crisidæ, *Busk* (pars), *Hincks* (Cyclostomata, Family I.).
Cupularia, *Lamx.* (Genus 84).
Canariensis, *Busk.*
Guinæensis, *Busk.*
Johnsoni, *Busk.*
Lowei, *Busk.*
monotrema, *Busk.*
Owenii, *Gray.*
pyriformis, *Busk.*
stellata, *Busk.*
Cyclicopora, *Hincks.*
longipora, *Macgil.*

D.

Diachoris, *Busk* (Genus 31).
- bilaminata, *Hincks.*
- Buskiana, *Hutton.*
- costata, *Busk.*
- crotali, *Busk.*
- elongata, *Hincks.*
- hirtissima, *Heller.*
  - form. robusta, *Hincks.*
- inermis, *Busk.*
- intermedia, *Hincks.*
- Magellanica, *Busk.*
  - *var. a.* distans, *Busk.*
- patellaria, *Moll.*
- quadricornuta, *Hincks.*
- spinigera, *Macgil.*

Diastopora (pt.), *Lamx.* (Cyclostomata, Genus 6).
- congesta, *D'Orb.*
- meandrina, *S. Wood.* (Mesenteripora).

Diastopora
- obelia, *Johnst.*
- patina, *Lamk.*
- Sarniensis, *Norman.*
- suborbicularis, *Hincks.*

Didymia, *Busk* (Genus 23).
- simplex, *Busk.*

Dimetopia, *Busk* (Genus 24).
- cornuta, *Busk.*
- spicata, *Busk.*

Diplopora, *Macgil.* (Genus 42).
- cincta (*Hutton's, M. cincta*).

Diporula, *Hincks.*
- verrucosa, *Peach.*

Domopora, *D'Orb.* (Cyclostomata, Genus 10).
- lucernaria, *Sars.*
- stellata, *Goldfuss.*
- truncata, *Jameson.*

E.

Electra, *Lamx.* (Genus 44).
- bellula, *Hincks.*
- cylindrica, *Busk.*
- ? distorta, *Hincks.*
- pilosa, *Linn.*
  - *var. a.* dentata, *Hincks.*
  - *β. var.* laxa, *Smitt.*
  - „ *γ.* (Pallas, sp. *Hincks.*)
- tricantha, *Lamx.*
- verticellata, *Lamx.*

Electrinidæ, *Busk* (Family XIII.).

Emma, *Gray* (Genus 11).
- crystallina, *Gray.*

Entalophora, *Lamx.* (Cyclostomata, Genus 5).
- australis, *Busk.*
- clavata, *Busk.*
- clavæformis, *Busk.*
- delicatula, *Busk.*
- Gallica, *D'Orb.*
- Indica, *D'Orb.*
- intricaria, *Busk.*
- orchadensis, *D'Orb.*
- parasitica, *Busk.*

Entalophora
- proboscidæ, *Forbes.*

Eschara, *Pallas* (Genus 64).
- elegantula, *D'Orb.*
- glabra, *Hincks.*
- gracilis, *Lamk.*
- perpusilla, *Busk.*

Escharidæ, *Busk* (pt. *Hincks*), (Family XXI.).

Escharoides, *Smitt* (Genus 68).
- occlusa, *Busk.*
- quincuncialis, *Norman.*
- rosacea, *Busk.*
- verruculata, *Smitt.*

Eucratea, *Lamx.* (Genus 2).
- chelata, *Linn.*
  - *Var. a,* repens, *Hincks.*
  - „ *β,* gracilis, *Hincks.*
- ambigua, *D'Orb.*

Eucrateadæ, *Busk* (pt. *Hincks*), (Family II.).

Euthyris, *Hincks* (Family Membraniporidæ).
- obtecta, *Hincks*, pp. 62 and 63.

F

G

H.

M.

Retepora
granulata, *Macgil.*
hirsuta, *Busk.*
Imperati, *Busk.*
Jacksoniensis, *Busk.*
lata, *Busk.*
laxa, *Hincks.*
lunata, *Macgil.*
Magellensis, *Busk.*
margaritacea, *Busk.*
marsupiata, *Smitt.*
microthyris (MS.), *Busk.*
monilifera, *Macgil.*
mucronata, *Busk.*
munita, *Macgil.*
Philippinensis, *Busk.*
phænicia, *Busk.*
plana, *Hincks.*
porcellana, *Macgil.*
prætenuis, *Hincks.*
producta, *Busk.*
serrata, *Macgil.*
simplex, *Busk.*

Retepora
sinuata, *Macgil.*
tessellata, *Hincks.*
Var. α, cæspitosa, *Busk.*
β, pubens, *Busk.*
tubulata, *Busk.*
umbonata, *Macgil.*
versipalma, *Blainv.* (sp.)
Victoriensis, *Busk.*
Var. Japonica, *Busk.*
Wallichiana, *Busk* & *Hincks.*
Reteporella, *Busk* (Genus 58).
flabellata, *Busk.*
myriozoides, *Busk.*
Reteporidæ, *Smitt* (Fam. XVIII.).
Rhabdozoum, *Hincks* (Eucrateidæ, Family II.).
Rhabdozoum.
Wilsoni, *Hincks.*
Rhyncopora, *Hincks* (Family Myriozoidæ, *Hincks*), (Genus 53 ?).
bispinosa, *Johnst.*, p. 101.
longirostris, *Hincks.*

S

Salicornaria, *Cuvier* (Cellaria, *Hincks*, Genus 47).
aciculata (MS.) *Busk.*
bicornis, *Busk.*
clavata, *Busk.*
crassa (MS.), *Busk.*
divaricata, *Busk.*
dubia, *Busk.*
farciminoides, *Cuvier.*
fistulosa, *Linn.* (Cellaria, *Hks*).
gracilis, *Busk.*
hexagonalis (MS.), *Busk.*
hirsuta, *Kirchenpauer.*
Johnsoni, *Busk.*
magnifica, *Busk.*
malvinensis, *Busk.*
simplex, *Busk* (Cellaria rigida, *Macgil.*).
sinuosa, *Hassall.*
tenuirostris, *Busk.*
variabilis, *Busk.*
Schizoporella, *Hincks* (Genus 72).
acuminata, *Hincks.*
Alderi, *Busk.*
aperta, *Hincks.*
argentea, *Hincks.*
armata, *Hincks.*

Schizoporella
auriculata, *Hassall.*
Var. alba, *Busk.*
„ ochracea, *Hincks.*
„ cuspidata.
biaperta, *Michelin.*
Var. eschariformis, *Waters.*
biserialis, *Hincks.*
biturrita, *Hincks.*
Cecillia, *Audouin.*
circinata, *Macgillivray.*
cinctipora, *Hincks.*
crassilebris, *Hincks.*
crassirostris, *Hincks.*
cribrilifera, *Hincks.*
cristata, *Hincks.*
cruenta, *Norman.*
Dawsoni(?), *Hks.* (S. torquata, *D'Orb.*, *Hincks*).
discoidea, *Busk.*
elegans, *D'Orb.*
fissurella, *Hincks.*
furcata, *Busk.*
hyalina, *Linn.*
Var. α, cornuta, *Hincks.*
„ β, incrassata.
„ γ, tuberculata.

Smittipora, *J. Jullien* (Genus 40 ?).
abyssicola, *Smitt.*
Steganoporella, *Smitt* (Genus 40).
magnilabris, *Busk.*
Neo-Zelanica, *Busk.*
Smittia, *Hincks.*
Steganoporellidæ, *Hincks* (see Family XIIa.).
Stiparia, *Hincks* (see Genus 20a).
annulata, *Mapleston.*
glabra, *Hincks.*
Stolonella, *Hincks* (see Genus 20b).
clausa, *Hincks.*

Stomatopora, *Bronn* (Cyclostomata, Genus 2).
compacta, *Norman.*
deflexa, *Couch.*
diastoporides, *Norman.*
dilatans, *Johnst.*
expansa, *Hincks.*
fasciculata, *Hincks.*
fungia, *Couch.*
granulata, *M.-Edw.*
incrassata, *Smitt.*
incurvata, *Hincks.*
Johnstonii, *Heller.*
major, *Johnst.*

T.

Tennysonia, *Busk* (Cyclostomata, Genus 9).
stellata, *Busk.*
Tessarodoma, *Norman* (Genus 76).
boreale, *Busk.*
Tubucellaria, *D'Orb.* (Genus 49).
cæca (MS.), *Busk.*
cereoides, *Ell. & Sol.*
fusiformis, *D'Orb.*
hirsuta, *Lamx.*
opuntioides, *Pallas.*
Tubucellaridæ, *Busk* (Fam. XVI.).
Tubulipora, *Lamk.* (Cyclostomata, Genus 3).
capitata, *Hincks.*

Tubulipora
Dawsoni, *Hincks.*
dichotoma, *D'Orb.*
fasciculifera, *Hincks.*
flabellaris, *Fabric.*
fimbria, *Lamk.*
lobulata, *Hassall.*
malacensis, *D'Orb.*
organizans, *D'Orb.*
perfragilis, *Hincks.*
pyriformis, *Busk.*
ventricosa, *Busk.*
Turritigera, *Busk* (Genus 59).
stellata, *Busk.*

U.

Umbonula, *Hincks* (Genus 78 ?).

Umbonula verrucosa, *Esper.*

V.

Vincularia, *Defrance* (Genus 39).
gothica, *D'Orb.*

Vincularia gothica, *D'Orb.*
Var. granulata, *Busk.*

For Lists of Synonyms, &c., from Hincks and Busk, see the end of the systematic arrangement, pp. 601–612.

PART II. SYSTEMATIC ARRANGEMENT: GENERA AND SPECIES.

a. CHEILOSTOMATA, *Busk.*

In this part of my labours I have compiled, from all available sources accessible to me, the name of every described species of marine polyzoa. It may be that some of the Australian species of Macgillivray and others are omitted; if so, I shall regret it: but the excuse I offer is, Australian works generally were not at my disposal.

SUB-ORDER. **CHEILOSTOMATA**, *Busk.*

DIVISION I. STOLONATA, *Carus.*

Family I. **Æteidæ**, *Busk & Hincks.*

Genus. Ætea, *Lamx.*

Family II. **Eucratiidæ**, *Busk* (pt. *Hincks*).

Genus.	Eucratea, *Lamx.*	Genus.	Pasythea, *Lamx.*
,,	Hippothoa, *Lamx.*	,,	Brettia, *Dyster.*

Family III. **Chlidoniadæ**, *Busk.*

Genus. Chlidonia, *Savigny.*

('Challenger' Report, p. 1.)

Family I. Æteidæ

= ÆTEIDÆ, *Smitt, Hincks*
= SCRUPARIADÆ (pars), *Busk,* 'Brit. Mus. Cat.'
= STOLONATA (pars), *Carus.*

'Zoœcia tubular, with a subterminal membranous area; partly erect and free, partly decumbent and adherent; uniserial.'—*Challenger Report*, p. 1.

It may be well to note that the characters of this family as given above from Mr. Busk differ in some respects from those of Mr. Hincks ('Brit. Mar. Pol.' p. 1), but chiefly in the fact that Mr. Hincks includes in his diagnosis the following: 'Tentacular sheath terminal above in a circle of *setæ*, which are everted during the expansion of the polypide.'

It is thus seen that the Æteidæ connect together two groups—the *Ctenostomata* on the one hand, and the *Cheilostomata* on the other. Professor Smitt, Mr. Hincks, and Mr. A. W. Waters ('Bay of Naples Bry.,' 1879) have already remarked on the peculiar structural features of this group, which has been fully referred to in the Fifth Report on Fossil Polyzoa ('Brit. Assoc. Rep.', 1884).

As in my previous Reports, I shall furnish the characters of the families, and the genera only of recent polyzoa, as given either by Mr. Hincks or Mr. Busk, but it will be impossible to furnish details of the species.

Genus 1. Ætea, *Lamouroux*

= ANGUINARIA, *Lamk., Johnston, Busk,* 1849
= FALCARIA, *Oken*
= ÆTEA, *Busk* ('Brit. Mus. Cat.'), *Smitt, Hincks, Waters,* &c.

'Zoœcia calcareous, tubular, erect, with a membranous area on one side; distributed along a more or less adherent, creeping fibre, dilated at intervals; orifice terminal. Oœcia, none.'—*Brit. Mar. Polyzoa*, p. 3.

'Orifice semicircular, subterminal.'—*Busk*, 'Challenger' Report, p. 2.

1. Ætea anguina, *Linn.*, 'Brit. Mar. Poly.,' 'Challenger' Report.
2. ,, recta, *Hincks*, 'Brit. Mar. Poly.,' p. 6.
3. ,, truncata, *Lansb.*, 'Brit. Mar. Poly.,' p. 8.
4. ,, dilatata, *Busk*, 'Brit. Mus. Cat.,' pt. i.

5. *Ætea* ligulata, *Busk*, 'Brit. Mus. Cat.'
6. „ Americana, *D'Orb.*, 'Voy. dans l'Amér. Mérid.,' *D'Orb.*
7. „ argillacea, *Smitt.*

Mr. Hincks says (*op. cit.* p. 3): 'Seven species of *Ætea* have been described, of which three occur on our own coast.' In the 'Challenger' Report only one species is recorded as present in the material furnished to Mr. Busk (*Æ.* anguina, *Linn.*), and this was found at five of the stations: i. 36, 30 fathoms; ii. 161, 33 fathoms; iii. 135A, 75, 110 fathoms; iv. 304, 45 fathoms; v. 162, 38 to 85 fathoms.

Family II. **Eucrateadæ**, *Busk*

= EUCRATEIDÆ (pars), *Hincks*, 'Brit. Mar. Poly.,' p. 10
= SCRUPARIADÆ (pars), 'Brit. Mus. Cat.'

'Zoœcium erect and free or decumbent, more or less ordinate. Zoœcia uni- or bi-serial, or geminate, pyriform, with a subterminal oblique orifice, unarmed.'—*Busk*, 'Challenger Report on Polyzoa,' p. 2.

In the classification of British Marine Polyzoa, Mr. Hincks places in his family the following genera—*Eucratea*, *Gemellaria*, *Scruparia*, *Huxleya*, *Brettia*, *Dimetopia*, and *Calwellia*. As will be seen, only four genera are admitted by Mr. Busk, all of which are stolonate.

Genus 2. Eucratea, *Lamouroux*.

'Zoœcium usually with a creeping adherent base, erect branching. Zoœcia calcareous, rising one from another singly. Aperture oblique, terminal or subterminal. Orifice semicircular, with a straight lower border. Branches springing from the front of a zoœcium below the aperture.'—*Busk*, 'Challenger Report.' (Mr. Hincks's diagnosis is very similar to above.)

1. Eucratea chelata, *Linn.* (*Hincks*, 'British Marine Polyzoa,' p. 14, pl. i. fig. 3; pl. ii. figs. 4–8; pl. iii. figs. 9–11.
2. Eucratea chelata, *var. α.* repens, *Hincks*, pl. i. fig. 3.
3. „ „ „ *β.* gracilis, *Hincks.*

Both Mr. Busk and Mr. Hincks limit, as above, the genus *Eucratea*, and only one species is described as British, but Mr. Waters (Bay of Naples Bry.) describes the following species, remarking that he 'did not find *E. chelata* at Naples, but it is reported to have been found in the Mediterranean.'—*Ann. Mag. Nat. Hist.*, 1879, p. 117.

4. Eucratea ambigua, *D'Orb.* This species, which closely resembles *E. chelata*, is a native of South America.

Nos. 1 and 3, Mr. Hincks says, are very abundant in Australia. The species varies very much and 'in an early stage of growth is often decumbent. A few cells are repent and adnate, and from these the erect shoots arise, and the zoarium then assumes its normal condition' (Hincks, p. 15). *Eucratea chelata* is the only species described by Mr. Busk in his 'Challenger' Report, p. 3.

Genus 3. Hippothoa, *Lamouroux*

= CATENICELLA (pars), *Blainv.* = MOLLIA (pars), *Smitt.* ? TEREBRIPORA, *D'Orb.*

'Zoœcia calcareous, decumbent, adherent, usually distant and connected by tubular prolongations. Branches given off from the sides of the zoœcium. Orifice orbicular, sometimes produced and subtubular, with a sinus in the lower border.'—*Challenger Report*, p. 4.

On account of this last character—the 'sinus' in the lower border—Mr. Hincks ('British Marine Polyzoa,' p. 286) places *Hippothoa* in his family group MYRIOZOIDÆ in association with *Schizoporella*. Prof. Smitt 'disallows the genus and ranks its members with species which are supposed to possess similar zoœcia, irrespective of the habit of growth' (*op. cit.* p. 287).

1. Hippothoa divaricata, *Lamx.*, *Hincks*, 'British Marine Polyzoa,' p. 288.
   Hippothoa divaricata, *var.* α, conferta, *Hincks*, p. 288.
   " " " β, carinata, *Norman*, p. 289.
   " " " γ, Patagonica, *Busk.*
2. " expansa, *Dawson* (*Hincks*, p. 291).
3. " flagellum, *Manzoni* (*Hincks*, p. 293).
4. " distans, *Macgillivray* (*Hincks*, 'Polyzoa,' Queen Charlotte Island Annals, June 1883.

Only two species of *Hippothoa* are described by Mr. Busk in the 'Challenger' Report, *H. divaricata* and *H. flagellum*, Manzoni. The first at Station 135 in from 60 to 1,000 fathoms, and the other at Station 151, off Heard Island, in 75 fathoms. The *H. expansa*, Dawson, is a northern species, and the British species are cosmopolitan in their geographical distribution.

Genus 4. Pasythea, *Lamouroux*

= CELLARIA (sp.), *Solander*. = LIRIOZOA, *Lamk*. = EPICAULIDIUM, *Hincks*.

In the 'Ann. Mag. Nat. Hist.' Feb. 1881, p. 156, Mr. Hincks described as new under the generic and specific name of *Epicaulidium pulchrum* the *Cellaria tulipifera* of Solander. In his 'Challenger' Report (pp. 3 and 5) Mr. Busk draws attention to this species when describing a new form previously referred to by Smitt in his 'Floridian Bryozoa.' As Mr. Hincks's genus is replaced by the older name, I have thought it best to retain his generic description intact, especially so as Mr. Busk's diagnosis differs from that of Mr. Hincks.

'Zoarum calcareous, composed of a creeping base and erect stems, made up of internodes linked together at their extremities by corneous joints, on which the zoœcia are borne in companies. Zoœcia erect, clavate, with a small oblique subterminal orifice, several united together longitudinally, so as to form a cluster; the clusters opposite free, except at the base, where they are attached by corneous joints to the internodes.' —*Hincks, op. cit.* p. 157.

In a corrigendum, 'Ann. Mag. Nat. Hist.' Aug. 1881, p. 135, Mr. Hincks says that the above species was figured and described by Ellis (edited by Solander) under the name of *Cellaria tulipifera*; Lamouroux referred it to his genus *Pasythea*; De Blainville and Lamarck gave its generic rank—one as Tuliparia, *Blainv.*, the other as Liriozoa, *Lamk.*

1. Pasythea tulipifera, *Solander*, *Lamx.* = EPICAULIDIUM PULCHRUM, *Hincks*.
2. Pasythea eburnea, *Smitt* (Florid. Bryoz., *Busk*) = GEMELLIPORA EBURNEA, *Smitt*.

The only locality that I have the species from is Brazil. The slide came into my possession with others from the same locality, marked 'Membranipora, sp.', and it was only after Mr. Hincks's description was published that I was able to name it. Lamouroux's description of the form and also the locality given by him are as follows:—[1]

'Pasithea tulipifera. Articulations in the form of clubs; cells three in number, united on one pedicle' ('Corallina'), p. 67, pl. iii. fig. 7, A.

'American seas, principally on the Jamaica coast.' The other species described by Lamouroux is a hydrozoon.

The only other genus of the Eucratiidæ of Busk is the following. I have adopted the diagnosis of Hincks:—

Genus 5. Brettia, *Dyster.*

'Zoarium erect, corneous, branched, branches given of from the top of a cell a little to one side, and facing in the same direction as the cell. Zoœcia uniserial, elongate, subtubular; aperture, terminal or sub-terminal, large, with the oral valve at the upper extremity; margin armed with spines. Oœcia unknown.'—*Brit. Mar. Pol.* pp. 27, 28.

1. Brettia pellucida, *Dyster.* 'Brit. Mar. Pol.' p. 28 pl. iv. figs. 6, 7. 'Quart Jour. Micr. Soc.' vi., 1858, p. 260 pl. xxi. figs. 3–5.
2. Brettia tubæformis, *Hincks.* 'Brit. Mar. Pol.' p. 28 pl. ii. fig. 2, pl. v. fig. 1 = *B. pellucida*, Norman, 'Brit. Assoc. Rep.', 1866, p. 196, &c.

The first of these species was found by Mrs. Brett at Tenby; a minute fragment of the second was dredged in The Minch by Mr. Norman. These are very rare forms, but anyone, after carefully examining the plates in Mr. Hincks's work, can easily recognise the difference between the two species.

3. Brettia australis, *Busk.* 'Challenger Report,' p. 7 pl. xxxiv. fig. 3.
4. Brettia cornigera, *Busk.* 'Challenger Report,' p. 7, pl. xxxiv. fig. 6.

As Mr. Busk by some oversight places the genus Brettia in two families in the 'Challenger Report,' I have merely indicated its position further on by the number 26 ? so as to keep the synopsis and text intact, and preserve the suggestions even of the author.

As to the numbered families and genera given in the Report, with the exception of Notamiidæ and one or two genera, which will be pointed out in the text, the whole of the present arrangement is that of Mr. Busk. As, however, Mr. Hincks has instituted several genera, and one or two families which are not accounted for, accepted, or referred to in the 'Challenger Report,' I have thought it wise to include these in the several divisions, but *unnumbered.* Mr. Hincks, therefore, is responsible for their position in certain families. His names will be found in his own synopsis—the second—in the introductory part of the present Report.

[1] The work of Lamouroux, referred to above, is his *Corallina*, translated by a lady. Ed. 1824.

Family **Eucratiidæ**, *Hincks.*

Genus. Rhabdozoum, *Hincks.*

(‘Annals and Mag. Nat. Hist.’, vol. x. ser. 5, 1882.)

‘Zoarium erect phytoid, composed of numerous celluliferous shoots, held together by a ramified stem, made up of bundles of radical fibres, given off from the inferior portion of the shoots; celluliferous shoots consisting of a cylindrical bi- or tri-furcate stem, which gives origin to the radical fibres, and also to erect chitinous rods, on the summit of which are borne two or three similar stems, more or less dichotomously divided. Zoœcia pyriform, ranged in linear series round an imaginary axis, so as to form cylindrical stems; aperture moderately large, sub-terminal oblique. Avicularia not stipitate.’—*Hincks.*

Rhabdozoum Wilsoni, *Hincks, op. cit.* p. 162 pl. viii. fig. 4.
Locality : Port Phillip Head, Victoria, *Mr. Bracebridge Wilson.*

Family III. **Chlidoniadæ**, *Busk.*

‘Zoœcium composed of upright, free, segmented stems, springing from a stolonate network. From the segments, after the first bifurcation, arise lateral branches consisting of chains of zoœcia arising from the back near the summit. Zoœcia bicamerate; unarmed.’—*Busk,* ‘Chal. Rep.’ p. 8.

Genus 6. Chlidonia, *Savigny* (1811)

= Eucratea, *Aud.* (?) Vorticella, *Linn. & Esper.*
= Cothurnicella, *Wyv. Thomson.*

‘Free portion of the zoœcium composed of segmented tubular stems with distant short branches, each springing from one of the internodes of the stem, and giving off numerous uniserial chains of zoœcia, one rising from the back of another near the top, and all looking one way. Zoœcia gibbous, pyriform, or attenuated downwards. Orifice prominent or sub-tubular, lower lip entire, straight. The cavity of the zoœcium divided into two chambers, the hinder of which is much curved, and alone communicates with the orifice and lodges the polypide.’—*Busk,* ‘Chal. Rep.’ p. 8.

Chlidonia cordiera, *Aud.* (*Busk,* ‘Chal. Rep.’ pl. xxviii. fig. 11)
= Eucratea cordiera, *Aud.*, ‘Ægypta,’ pl. xiii. fig. 3
= Clidonia cordiera, *D'Orb.*, ‘Pal. Fr.’ p. 40
= Cothurnicella dædala, *Wyv. Thomson,* ‘Nat. Hist. Rev.’ vol. v. p. 146.

This species is very generally distributed. Mr. Busk gives it as occurring at only one station—No. 186. Mr. A. W. Waters describes it in his ‘Bay of Naples Bryozoa.’ Wyville Thomson's Australian form is from Port Phillip. It is also met with at the Canaries, ‘and I have specimens from the coast of Calvados, from Nice, Egypt (Sir Jos. Banks), and Tyre (*Miss Gatty*).’—*Busk,* ‘Chal. Rep.’ p. 9.

Division II. RADICELLATA.

Group A. Cellularina.

(*Busk*, 'Challenger Report,' p. 9.)

Family IV. **Catenariadæ**, *Busk*.

1850–2 = Catenariadæ (pars), *D'Orb.*
1852 = Catenicellidæ, *Busk.*
" = Scrupariadæ (pars), *Busk.*
" = Cellularieæ (pars), *Smitt.*

'Zoœcium radicate, segmented, internodes, except at a bifurcation, formed of a single zoœcium.'—*Busk*, 'Chal. Rep.' p. 9.

I. Catenicella, *Blainville.*
II. Catenaria, *Savigny.*

Genus 7. Catenicella, *Blainville.*

'Internodes usually unicellular, the zoœcia arising one from the upper and back part of another, by a corneous tube, all facing the same way and forming dichotomously divided branches of an erect phytoid zoœcium. The zoœcium at each bifurcation geminate; each zoœcium with two lateral, usually trilocular, processes (*alæ*). Oœcia either subglobose and terminal or immersed, and placed below the orifice of a zoœcium in front.'—*Busk*, 'Chal. Rep.' p. 10.

Mr. Busk describes the eight Challenger species in the collection, and figures only a portion of them. The first four belong to the section § *α. Fenestratæ*, the other to the section § *β. Vittatæ.* Since the publication of the 'Brit. Mus. Catalogue' (1852) many new species have been added to Mr. Busk's original list, and described and partially figured by Australian students. In the following list I have given the whole of the species known to me, and Mr. Waters has been able to add to the recent species many new fossil forms from the Australian tertiary beds, details of which will be found in my fifth 'Brit. Assoc. Rep. on Fossil Polyzoa,' 1884, Montreal.

1. Catenicella ventricosa, *Busk*, 'Brit. Mus. Cat.'
   " *var.* maculata, *Busk* (*op. cit.* pl. iii. figs. 4, 5).
2. " hastata, *Busk* (*op. cit.* pl. ii. figs. 3, 4).
3. " plagiostoma, *Busk* (*op. cit.* pl. v. figs. 1, 2).
4. " cribraria, *Busk* (*op. cit.* pl. v. figs. 3, 4); 'Chal. Rep.' p. 11, pl. i. fig. 6.
5. " sacculata, *Busk*, 'Chal. Rep.' pl. i. fig. 7.
6. " elegans, *Busk*=(?) *Eucratea Contei*, *Aud.*
   = *C. Savignyi*, *Blainv.*
   = *C. elegans*, *Busk*, 'Brit. Mus. Cat.' vol. i.; 'Chal. Rep.' pl. i. figs. 2, 3, 5.
7. " umbonata, *Busk*, 'Brit. Mus. Cat.'; (*var.*) 'Chal. Rep.' pl. i. fig. 1.
8. " pulchella, *Mapleston* ('Jour. Mic. Soc.', Victoria; 'Chal. Rep.' pl. i. fig. 4).
9. " lorica, *Busk*, 'Brit. Mus. Cat.'
10. " aurita, *Busk* " "
11. " amphora, *Busk* " "
12. " margaritacea, *Busk* " "

13. Catenicella forinosa, *Busk*, 'Brit. Mus. Cat.'
14. " perforata, *Busk* " "
15. " ringens, *Busk* " "
16. " cornuta " "
17. " gibbosa, *Busk* " "
18. " taurina, *Busk* " " (pl. xi.)
19. " carinata " "
20. " alata, *Wyv. Thoms.*, 'On New Gen. and Sp. of Polyzoa.'
21. " Harveyi, *W. Thoms.* " " "
22. " Dawsoni, *W. Thoms.* " " "
23. " castanea, *Wyv. Thoms.* " " "
24. " crystallina, *W. Thoms.* " " "
25. " Buskii, *Wyv. Thoms.* " " "
26. " geminata, *W. Thoms.*
27. " rufa, *Macgil.*
28. " concinna, *Macgil.*
29. " Wilsoni, *Macgil.*, 'On some New Sp. of *Catenicella*, &c.'
30. " gracilenta, *Macgil.*
31. " intermedia, *Macgil.*
32. " utriculus, *Macgil.*
33. " fusca, *Macgil.*
34. " Hannafordii, *Macgil.*
35. " insignis, *Macgil.*
36. " ponderosa, *Macgil.*
37. " (Catenicellopsis) deliculata, *Macgil.*

Mr. Hincks, in one of his papers—'Contributions towards a General History of Marine Polyzoa'—refers only to *Catenicella*, and says that though he has several species by him he would not describe or refer to them until the whole of the papers on the group were in his hands.

Genus 8. Catenaria, *Savigny*.

1811 = Catenaria (pars), *Savigny*, *D'Orb.*, 'Palæont.'
Eucratea (pars), *Aud.* (not Lamk., Blainv.)
1852. Alysidium (pars), *Busk*, 'Brit. Mus. Cat.'

'Zoarium erect or free, dichotomously branched; the Zoœcium at each bifurcation single. Zoœcia elongate, sub-tubular or trumpet shaped, without a frontal aperture. Mouth orbicular or semi-orbicular. Avicularia present or absent.'—*Challenger Report*, p. 14.

1. Catenaria Lafontii, *Aud.*, *Ægypta*, pl. xiii. fig. 2. A. W. Waters's 'Bay of Nap. Bryoz.' (Typical species of genus, *Busk.*)
= *Alysidium Lafontii*, *Busk*, 'Brit. Mus. Cat.'
2. " attenuata, *Busk*, 'Chal. Rep.' pl. ii. fig. 1.
3. " bicornis, *Busk*, 'Chal. Rep.' pl. ii. fig. 2.
4. " diaphana, *Busk*, 'Chal. Rep.' pl. ii. fig. 3
= *Scruparia diaphana*, *Busk*, 'Quart. Jour. Mic. Soc.,' vol. viii. p. 281, pl. xxxi. fig. 1.

Family V. **Cellulariadæ**, *Busk*

= Cellulariadæ, *Busk*, Crag Polyzoa; *Hincks*
= Cellulariadæ, 'Brit. Mus. Cat.'
= Cellularidæ (pars), *Johnston*
= Cellularicæ (pars), *Smitt.*

'Zoarium articulated, phytoid, erect, dichotomous, bi-, tri-, or multiserial. Zoœcia rising from a broad base, alternate, all facing the same way; a large oval membranous aperture. Avicularia, when present, sessile, and either lateral or anterior.'—*Challenger Report*, p. 15.

Mr. Busk, in the above report, divides the family into the following seven genera:—

1. Cellularia, *Pallas* (pars) § α, *aperta.*
   § β, *fornicata.*
2. Menipea, *Lamouroux*, Sections α and β.
3. Emma, *Gray.*
4. Scrupocellaria, *Van Beneden.*
5. Canda, *Lamouroux.*
6. Nellia, *Busk.*
7. Caberea, *Lamouroux*, Sections α and β.

Mr. Hincks, however, in his 'Brit. Mar. Polyzoa,' accepts the family Cellulariidæ, but his description differs in some few particulars from that of Mr. Busk.

'Zoœcia in two or more series closely united and ranged in the same plane; avicularia and vibracula, or avicularia only, almost universally present, sessile. Zoarium erect, dichotomously branched.'—*Hincks*, 'Brit. Mar. Pol.' p. 30.

Genera: Cellularia, *Pallas.*
Menipea, *Lamouroux.*
Scrupocellaria, *Van Beneden.*
Caberea, *Lamouroux.*

This important group has a very wide distribution. In his admirable introduction appended to the description of the family, Mr. Hincks (pp. 30–32) points out many peculiar modifications of the appendicular organs, and also of the radical fibres, 'by means of which the tufted zoaria are attached' to foreign bodies. There is still much to be learnt respecting these same radical fibres; and in speaking of the fibres, especially of *Scrupocellara reptens*, some curious modifications are pointed out. Mr. George Busk, in his paper on 'A Peculiar Form of Polyzoa closely allied to *Bugula*' ('Quart. Jour. Mic. Soc.' vol. xxi. new ser.), wherein he speaks of the 'radical and connecting tubes, like the avicularia and vibracula representing modified zooids.' This fact seems to be generally admitted, but still many minute particulars are pointed out by Mr. Busk in several species; and the student would do well to refer to this special paper, and also to the introduction of Mr. Hincks, previously referred to.

Genus 9. Cellularia, *Pallas.*

'Zoarum jointed. Zoœcia in two or three series, many in each internode, contiguous; dorsal surface perforated. Avicularia and vibracula usually wanting; occasionally an avicularium on a few of the cells of an internode.'—*Brit. Mar. Polyzoa*, p. 33.

1. Cellularia Peachi, *Busk*, 'Ann. Mag. Nat. Hist.' 2nd series, pl. vii. figs. 1–4. 'Brit. Mus. Cat.' i. 20. 'Brit. Mar. Polyz.' vol. i. p. 34, pl. v. figs. 2–5. Geographical range chiefly northern, British and American.

In the 'Challenger Report' Mr. Busk describes five new species of *Cellularia*, and remarks on the original specimen of *C. Peachii* as being entirely devoid of the cusp,[1] which Mr. Hincks speaks of as being present in the 'only British species'—*Cellularia Peachii*—that is known to him.

2. Cellularia cuspidata *Busk*, 'Brit. Mus. Cat.'
   = C. monotrypa, *Busk*, 'Voy. of Rattlesnake.'
3. „ crateriformis, *Busk*, 'Chal. Rep.' (pl. iii. fig. 1).
4. „ cirrata, *Busk*, 'Chal. Rep.' (pl. ii. fig. 4).
5. „ quadrata, *Busk*, 'Chal. Rep.' (pl. v. fig. 5).
6. „ biloba, *Busk*, 'Chal. Rep.' (pl. iii. fig. 2).
7. „ elongata, *Busk* (n. sp. ?), 'Chal. Rep.' pl. iii. fig. 3.
? „ ornata,[2] *Busk*, 'Brit. Mus. Cat.'
   = Menipea flabellata (?).

These species have a wide geographical range, and some of the specimens were dredged from great depths—2,650, 1,900, 1,425, and 900 fathoms—while others were derived from comparatively shallow depths—28 and 75 fathoms. The allied Australian species, *C. cuspidata* and *C. ornata*, 'closely resemble,' says Mr. Hincks, '*C. Peachii* in general character; but in *C. ornata* we meet with avicularia, . . . which are most sparingly developed and of a peculiar type. *C. Peachii* is totally destitute of appendicular organs.'—*Brit. Mar. Polyzoa*, p. 33.

Speaking of *C. cirrata*, *Busk*, Mr. Busk remarks 'that the general structure of the species is very peculiar, and together with other characters might perhaps justify its erection into a distinct genus.' There was only one specimen in the 'Challenger' collection, and this is both well described and well illustrated in the Report.

Genus 10. Menipea, *Lamouroux*

= Tricellaria (sp.) *Fleming*, *Blainville*, *Gray*
= Cellarina (pars) *Van Beneden*
= Cellularia (pars) *Johnst.*, *Smitt.*

'Zoœcia oblong, widest above, attenuated and often elongated downwards; imperforate behind, with a sessile lateral avicularium (often wanting), and usually one or two avicularia on the front of the cell. No vibracula. Zoarium jointed.'—*Brit. Mar. Polyzoa*, p. 36.

Mr. Busk divides the species of *Menipea* into two sections, § α. *Fornicatæ* and β. *Apertæ*. In a note ('Chal. Rep.' p. 15) on *Fornicatæ*, Mr. Busk says, 'A better term would have been "scutatæ," but as Prof. Smitt has introduced the term "*fornix*" for what I had originally named "operculum," now generally employed for the oral valve, I have adopted his term.'

1. Menipea ternata, *Ell. & Sol.* (*Hincks*, p. 38, pl. vi. figs. 1–4).
   „ „ British, chiefly northern.
   „ „ *Var.* gracilis, *Smitt*, Arctic form.
   = Cellularia ternata (forma gracilis), *Smitt.*
2. „ gracilis, *Busk*, 'Polyzoa N. Polar Exped.' (No. 14.)
   In a note, p. 40, Mr. Hincks says, 'I have received

[1] There is no cusp in the Shetland specimens given to me by Miss E. C. Jelly; originally from C. W. Peach's dredgings, 1864.
[2] See *Menipea flabellum*, Lamouroux.

from Mr. Peach two or three minute fragments of a *Menipea* from Shetland, in which the form of the cells is that of the *gracilis* variety. They also show a larger number in the internode than is characteristic of the normal *M. ternata*.' But on account of their imperfect condition Mr. Hincks was unable to say whether they should be referred to the variety, or to one of the closely related forms, *M. arctica*, or to

3. Menipea Smittii, *Norman*
   = Cellularia ternata (forma duplex), *Smitt.*
4. „ Jeffreysii, *Norman* (*Hincks*, pl. ix. figs. 1, 2), 'Quart. Jour. Mic. Soc.' 1868.
5. „ compacta, *Hincks*, 'Ann. Mag. N. Hist.' Dec. 1882.
   Var. triplex, *Hincks* „ „ „
6. „ cyathus, *Wyv. Thoms.*
7. „ arctica, *Busk.*
   Given as *var.* M. ternata, *var.* gracilis, *Smitt.*

In the 'Challenger Report' nine species are described by Mr. Busk, five of which are new.

§ *a. Fornicatæ.*

8. Menipea benemunita *Busk*, 'Chal. Rep.' pl. iv. fig. 4.
9. „ aculeata, *D'Orb.*, 'Chal. Rep.' pl. iv. fig. 2
   = Tricellaria aculeata, *D'Orb.*
   = Ternicellaria aculeata, *D'Orb.*
   = ? Menipea feugensis, *Busk*, 'Brit. Mus. Cat.'
10. „ clausa, *Busk*, 'Chal. Rep.' pl. iv. fig. 5.
11. „ flabellum, *Lamx.*, 'Chal. Rep.' p. 21
    = Cellularia ornata, *Busk*, 'Brit. Mus. Cat.'
    = ? Menipea flabellum, *Lamx.*
    Cellaria flabellum, *Ell. & Sol.*
12. „ flagellifera, *Busk*, 'Chal. Rep.' pl. iv. fig. 1.
13. „ Marionensis, *Busk*, 'Chal. Rep.' pl. iv. fig. 3; pl. xiv. fig. 9.
14. „ triseriata, *Busk*, 'Chal. Rep.' p. 21, 'Brit. Mus. Cat.'
15. „ cirrata, *Lamx.*, 'Chal. Rep.' p. 22
    = Cellaria cirrata, *Ell. & Sol.*
    = Cellaria crispa, *Pallas.*
    Tubularia cirrata, *Esper.*, *Seba.*
16. „ pateriformis, *Busk*, 'Chal. Rep.' pl. iv. fig. 4.
17. „ compacta, *Hincks*, form triplex, *Hincks.*
    Pol. Queen Charlotte Islands, 'Ann. Mag. Nat. Hist.' Dec. 1882.
18. „ marginata, *Hincks*, Polyzoa of Victoria, Australia, 'Ann. Mag. Nat. Hist.' p. 227, pl. ix. fig. 5. *Locality*: Port Phillip Head.
19. „ Buskii, *Wyv. Thoms.*

Genus 11. Emma, *Gray*

= Emma, *Gray*, *Busk*, 'Voy. of Rattlesnake,' 'Brit. Mus. Cat.' p. 27; *T. W. Hutton.*

Menipea (sp.) *Wyville Thomson; Hincks.*

'Zoœcia in conjoined pairs or triplets in each internode (not opposite), much expanded above and contracted below. Upper part of front occupied by a wide sub-triangular bordered area, partially filled in by a granular lamina, and with a sub-orbicular membranous aperture. A lateral sessile avicularium placed below the level of the aperture.'—*Busk*, 'Chal. Rep.' p. 22.

In his 'British Marine Polyzoa' Mr. Hincks disallows the genus *Emma,* and he places the name among the synomyms of the genus *Menipea.* Notwithstanding this, Mr. Busk restores the only species in the 'Challenger' material to its old place, as—

Emma crystallina, *Gray*, 'Chal. Rep.' p. 23
= E. crystallina, *Busk*, 'Brit. Mus. Cat.'

Genus 12. Scrupocellaria, *Van Beneden*

= Canda, sp., *Busk* = Bicellaria, sp., *Blainv.*
Cellularia, *Waters*, 'Bay of Nap. Bry.'

'Zoarium jointed. Zoœcia numerous in each internode, rhomboid; aperture with or without an operculum; a sessile avicularium placed laterally at the upper and outer angle, and a vibraculum in a bend or sinus on the lower part of the dorsal surface; frequently an avicularium on the front of the cell.'—*Hincks*, 'Brit. Mar. Pol.' p. 43.

As species of *Scrupocellaria* range backward in time from the present seas to the Miocene of Austria-Hungarian deposits, it is not surprising that many synonyms must necessarily fall under a few of the well-marked specific forms. Mr. Hincks has been exceptionally careful in his diagnosis of the five British forms, as the student will be pleased to find when working up the forms which are widely and generally distributed round our coast. Mr. Waters extends the area of three British species in his 'Bry. Bay of Naples.'

α. Without an operculum.

1. Scrupocellaria scruposa, *Hincks*, pl. vii. figs. 8–10.
2. „ elliptica, *Reuss*, *Hincks*, pl. vi. figs. 5, 6
= S. inermis, *Norman.*

β. With an operculum.

3. „ scabra, *Van Ben.*, *Hincks*, pl. vi. figs. 7–11.
4. „ scrupea, *Busk*, *Hincks*, p. vii. figs. 11–14.
5. „ reptans, *Linn.*, *Hincks*, pl. vii. figs. 1–7.

These are the whole of the British species given by Mr. Hincks. Mr. A. W. Waters, in his 'Bay of Naples Bryozoa,' gives as *Cellularia S. reptans*, *S. scruposa*, and *S. scrupea.*

In his 'Challenger Report,' Mr. Busk describes five species:—

6. Scrupocellaria Macandrei, *Busk*, 'Chal. Rep.' pl. xi. fig. 4
= S. Macandrei, *Busk*, 'Brit. Mus. Cat.'
7. „ ciliata, *Aud.*, 'Chal. Rep.' pl. xi. fig. 5
= S. diadema, *Busk*, 'Brit. Mus. Cat.'
8. „ ornithorhyncus, *Wyv. Thoms.* 'Chal. Rep.' pl. vi. fig. 6
= ? S. clypeata, *Haswell.*

9. Scrupocellaria pilosa, *Aud.*, 'Chal. Rep.' pl. xi. fig. 7
= Crisia pilosa, *Savig.*, 'Egypt.'
10. „ securifera, *Busk*, 'Chal. Rep.' pl. xi. fig. 2.

Mr. Hincks, in his various contributions, adds to the number of species which he describes or figures in the papers referred to.

11. Scrupocellaria varians, *Hincks*, Polyzoa of Queen Char. Is., 'Ann. Mag. Nat. Hist.,' Dec. 1882, pl. xix., figs. 1–10.
12. „ brevisetis, *Hincks*, *op. cit.* No figure. Bears some resemblance to S. scrupea.
13. „ obtecta, *Haswell*, *Hincks*, Contributions, &c. 'Ann. Mag. Nat. Hist.,' March 1883, p. 193, pl. vi. fig. 1.
14. „ cervicornis, *Busk* (*op. cit.* p. 193. No. fig.).
15. „ diadema, *Busk*, 'Brit. Mus. Cat.,' *Hincks*, 'Ann. Mag. Nat. Hist.,' May 1884. Polyzoa of India.

In his 'British Mus. Catalogue' Mr. Busk gives the following additional species:—

16. Scrupocellaria cyclostoma, *Busk*.
17. „ ferox, *Busk*.
18. „ Delilei, *Busk*.
19. „ Maderensis, *Busk*.
20. „ inermis, *Busk*.

The radical fibres of the different species of *Scrupocellaria* are a very interesting study, but more on account of their position and character than as means of distinguishing the difference between species by means of them alone. In *S. scruposa* they are slender and smooth, and given off at the lower part of the zoarium. In *S. scabra* they are long and slender, and scattered over the whole of the zoarium. In *S. reptans* the radical fibres are either simple and given off as anastomosing fibrils forming a netted disc, or toothed. Two forms are present in the different species. In one they are simply tubes, in another they are, as Mr. Hincks says, 'veritable grapnels.' In this form 'the fibre is covered for about two-thirds of its length with sharp, recurved, hook-like processes, and is converted into an admirable prehensile organ, which, when plunged into the soft sarcode of the sponge or other yielding substance, holds the polyzoon, like an anchor, to its place.' Ellis noticed these hook-like processes, and Couch, in his 'Cornish Fauna,' also noticed and recorded several peculiarities in the modes of attachment to other polyzoa. These hooked fibres are not, however, found on recent species only. In some of the Carboniferous *Fenestella*, hooked spines, though considerably more robust than any which now exist, are prominent features in the zoarium, and in all probability their purposes were the same in the economy of the species. Mr. Busk and Mr. Hincks's comments are well worth special study by the student.

Genus 13. Canda, *Lamouroux*

= Canda, *Lamx.*, *Blainv.* (pars), *D'Orb.*, and *Busk*, 'Brit. Mus. Cat.'
Scrupocellaria (pars), *Hincks*.

'Branches biserial, dichotomous, connected by transverse chitinous tubes, inserted at both ends into a vibracularium. No lateral avicularia, and the anterior avicularia when present placed on a special median tract, or on the summit of the oœcia. A vibracularium lodged in a sinus behind; flagellum short, flattened, not toothed. With or without a pedunculate fornix.'—*Busk*, 'Chal. Rep.' p. 25.

1. Canda arachnoides, *Lamx.*, 'Chal. Rep.' p. 25
   = Cellaria filifera, *Lamk.*, vol. ii. p. 177.
2. „ simplex, *Busk*, 'Chal. Rep.' p. 26, pl. xiv. fig. 8.
3. „ retiformis, *Smitt*, 'Florid. Bry.' (See following remarks.)

The Canda arachnoides, *Lamx.*, is abundant and fine in the Australian seas; but as the C. simplex is an Atlantic species, Mr. Busk's remarks on the form are very appropriate. 'In the "Challenger" collection this form is represented by only one or two minute fragments, in pretty good condition, but which would have been insufficient for its determination had I not been in possession of specimens of obviously the same form from the Gulf of Mexico. . . . It is a remarkable circumstance that a second species of Canda also occurs in the Gulf of Mexico, which has been described by Prof. Smitt (Florid. Bry., pt. I. p. 16, pl. v. figs. 43–46), under the not very well chosen name of *Caberea retiformis*.'—*Busk*, 'Chal. Rep.' p. 26.

Lamouroux's figure of C. arachnoides is good, and his description is well worth giving. 'Frondescent, fan-shaped, and dichotomous polypidom. Branches united by small lateral and horizontal fibres. Cells alternate, united, placed on only one surface, and not projecting.' 'Flex. Coral,' p. 57, pl. ii. figs. 6, *a b c d*.

Locality: On the rocks of Tamor.

Genus 14. Nellia, *Busk*

= Salicornaria (pars.), *Bk.*, 'Voyage of Rattlesnake,' vol. i. p. 367
= Nellia, *Bk.*, 'Brit. Mus. Cat.' vol. i. p. 18. *Smitt.*

'Zoarium articulated, internodes short, quadrangular. Zoœcia quadriserial, front flat or convex at bottom. The greater part of the front occupied by a large aperture; border prominent, especially above, smooth and thick. Orifice quite at the summit. Oœcia absent.'—*Chal. Rep.* p. 26.

1. Nellia oculata, *Busk*, 'Chal. Rep.' p. 27
   = N. oculata, *Bk.*, 'Brit. Mus. Cat.'
   = N. oculata, *Smitt*, 'Florid. Bry.'
   = N. oculata, *Macgil.*, 'Nat. Hist. Vict.'
2. „ simplex, *Busk*, 'Chal. Rep.' pl. v. fig. 6; and 'Brit. Mus. Cat.' p. 19.

Genus 15. Caberea, *Lamx.*

= Selbia, *Gray*; Flabellaria, *Gray*; Canda, *D'Orb.*

'Zoarium not articulated. Zoœcia not articulated, sub-quadrangular or ovate, with a very large aperture. Sessile avicularia on the side and front of the cells, the lateral avicularium minute. Vibracular cells very large, placed in two rows, stretching obliquely downwards across the

back of the zoœcia, which they almost cover, to the median line, notched above and traversed through a great portion of their length by a shallow groove. Setæ usually toothed on one side.'—*Hincks*, 'Brit. M. Pol.' p. 57.

1. Caberea Ellisii, *Flem.* (*Hincks*, p. 59, pl. viii. figs. 6–8). Arctic species, ranging to the more northerly portions of our coast, and to Labrador and Maine.
2. ,, Boryi, *Audouin* (*Hincks*, p. 61, pl. viii. figs. 9–11). 'Almost cosmopolitan.' Egypt, Adriatic, New Zealand, Australia: S. Patagonia; Strait of Magellan, &c.
3. ,, Hookeri, *Busk*, 'Brit. Mus. Cat.' vol. i. p. 39. This Mr. Hincks places as synonymous with C. Ellisii, *Flem.*, and the C. zelanica, *Busk* ('Voy. Rattlesnake,' vol. i. p. 378), as the same as C. Boryi, *Aud.*

In speaking of the vibracula, &c. of C. Boryi, Mr. Hincks says (p. 58, *op. cit.*): 'In this species there not only are the individual appendages highly developed, but the whole company of them attached to a colony are brought into combined and harmonious action. It must be left to future observation to determine the precise structural conditions on which these remarkable movements depend; but they certainly seem to imply the *existence*[1] *of a nervous system, distinct from that of the individual polypides, by which the vibracular zooides are controlled and brought into relation.*'

4. Caberea grandis, *Hincks*, Contributions, &c., 'Ann. Mag. Nat. Hist.' July 1881, pl. iii. figs. 4 *a*, *b*, *c*. Off Curtis Is. (*Capt. Warren*).

Mr. Busk in his 'Challenger Report' describes six species of *Caberea*, three of which are new.

§ *α*. fornicatæ.

5. Caberea rostrata, *Busk*, 'Chal. Rep.' pl. xxxii. fig. 4.
6. ,, crassemarginata, *Busk*, 'Chal. Rep.' pl. xi. fig. 1.
7. ,, Darwinii, *Busk*, 'Chal. Rep.' pl. xxxii. fig. 6
   = C. patagonica, *Busk*, 'Brit. Mus. Cat.'
   = C. zelanica, *Busk*, 'Voy. of Rattlesnake.'
8. ,, rudis, *Busk*, 'Chal. Rep.' p. 30, and 'Brit. Mus. Cat.'
9. ,, minima, *Busk*, 'Chal. Rep.' pl. xxxii. fig. 5.

§ *β*. apertæ.

10. ,, lata, *Busk*, 'Chal. Rep.' p. 30, pl. xi. fig. 3
    = 'Brit. Mus. Cat.'; 'Voy. of Rattlesnake.'
11. ,, Lyallii, *Busk*, 'Chal. Rep.' p. 29
    = Selbia zelanica, *Gray*.

This name is substituted by Mr. Busk for Gray's New Zealand species (*Selbia Zelanica*), after having fully satisfied himself that the species is quite distinct from '*Caberea boryi*, under which appellation, both I and other authors have confounded two or three quite distinct species.'—*Busk*, 'Chal. Rep.' p. 29.

[1] Italics mine.

Family VI. Bicellaridæ.

In the family group bearing the above name Mr. Busk ('Crag Polyzoa,' p. 15) placed three genera—*Bicellaria*, *Halophila*, and *Bugula*. Mr. Hincks, in the 'Brit. Mar. Polyzoa,' retains the family name which includes the following genera :—

Genus Bicellaria, *Blainville* ; Genus Beania, *Johnston* ;
„ Bugula, *Oken* ;

remarking that the first and last of the three are linked together by the genus *Bugula* and the genus *Diachoris*. . . . *D. Spinigera*, Macgil, . . . in a young state . . . is hardly distinguishable from a *Beania*, pp. 65, 66. In his paper (Contributions towards a General History of the Marine Polyzoa, 'Ann. Mag. Nat. Hist.', February 1881, p. 157), Mr. Hincks includes in the family, Diachoris, *Busk*.

In the 'Challenger Report,' Mr. Busk adheres to his original family name, but he adds to the number of the genera by including *Kinetoskias*, Koren and Dan., and Ichthyaria, *Busk*.

'Zoœcia, rather loosely united in two or more series, or disjunct; obconic, or boat shaped, the aperture usually occupying a large proportion of the front.—Avicularia, when present, capitate; pedunculate, and jointed. Zoarium not articulated ; erect and phytoid, or composed of a number of cells connected by tubular processes.'—*Hincks*, p. 64.

In the 'Challenger Report,' Mr. Busk describes the character of the family somewhat different from the above :—

Zoœcia turbinate or sub-turbinate, biserial, the two series more or less disjunct. Aperture large, directed obliquely upwards. Avicularia, when present, usually pedunculate and capitate or trumpet shaped ; rarely sessile, not articulated, and placed either on the anterior or posterior aspects. P. 32.

Genus 16. Bicellaria, *Blainville*.

'Zoarium erect, phytoid. Zoœcia turbinate or in the form of a cornucopia, loosely united, more or less free above ; aperture looking more or less upward, directed obliquely inwards below ; inferior portion of the cells sub-tubular, usually much produced. Avicularia, when present, jointed and capitate. No vibracula.'—*Hincks*, p. 66.

1. Bicellaria ciliata, *Linn.* *Hincks*, p. 68, pl. viii. figs. 1–5.
   British form, but it has a rather restricted geographical range, including North America (*Kirchenpauer*), and a variety in South Africa (*Hincks*).
2. „ Alderi Busk, *Hincks*, p. 70, pl. ix. figs. 3–7
   = B. unispinosa, *Sars*.
   Both the Brit. localities and also the geographical range of this species are restricted.
3. „ gracilis, *Busk*, 'Brit. Mus. Cat.'
4. „ grandis, „ *ibid.*
5. „ tuba, „ *ibid.* p. 42, pl. xxxi.

Australian forms. In *B. tuba* there is a fixed avicularium borne at the top of a tall spinous process ; consequently, as Mr. Hincks remarks, this species forms an exception to the latter part of the diagnosis of the genus given above. 'Avicularia,' &c.

In the 'Challenger Report,' Mr. Busk describes seven species, five of which are new.

1. Bicellaria navicularis, *Busk*, 'Chal. Rep.' pl. vii. fig. 2.
2. „ pectogemma, *Goldstein*, 'Chal. Rep.' pl. vii. fig. 1. Goldst. Pro. Roy. Soc. Vict. 1881.
3. „ infundibulata, *Busk*, 'Chal. Rep.' pl. vi. fig. 2.
4. „ bella, *Busk*, 'Chal. Rep.' pl. vi. fig. 4.
5. „ moluccensis, *Busk*, 'Chal. Rep.' pl. vi. fig. 4.
6. „ glabra, *Hincks*, 'Chal. Rep.' pl. vi. fig. 1 = Stirparia glabra, *Hincks*, 'Ann. Mag. Nat. Hist.' ser. v. vol. xi. p. 195.
7. „ macilenta, *Busk*, 'Chal. Rep.' pl. xxxii. fig. 1.

In certain remarks ('Chal. Rep.' p. 36) Mr. Busk justifies his adoption of these specific names, to the whole of which I direct the attention of the student, as without the plates and diagnoses it would be useless to quote extracts.

Genus 17. Bugula, *Oken*.

This genus has a number of synonyms, for which see Hincks, 'Brit. Mar. Polyzoa'; but one peculiar form, not given by Mr. Hincks, is the subject of a rather elaborate paper by Mr. Busk which will be referred to further on.

1. Bugula avicularia, *Linn.; Hincks*, p. 75, pl. x. figs. 1–4 = Ornithopora, id. *D'Orb.; Pal.; Fr.*
2. „ turbinata, *Alder; Hincks*, p. 715, pl. x. figs. 5–8.
3. „ flabellata, *J. V. Thompson; Hincks*, p. 80, pl. xi. figs. 1–3 = Ornithoporina avicularia, *D'Orb.*
4. „ calathus, *Norman; Hincks*, p. 82, pl. xi. figs. 4–6.
5. „ plumosa, *Pallas; Hincks*, p. 84, pl. xii. figs. 1–5.
6. „ gracilis, *Busk*, 'Quart. Jour. Mic. Soc.' vi. p. 125. *Var.* uncinata, *Hincks*, p. 86, pl. xv. figs. 1–4; pl. xii. figs. 6, 7.
7. „ purpurotincta, *Norman; Hincks*, p. 89, pl. xii. figs. 8–12.
8. „ Murrayana, *Johnst.; Hincks*, p. 92, pl. xiv. figs. 2–9.

These are the whole of the British forms given by Mr. Hincks, some of which have a very wide range around our coast; and the geographical range is also very varied. In Mr. Waters's 'Bry. Bay of Naples' he records as Mediterranean forms—

1. Bugula avicularia, *Pallas* = B. turbinata, *Hincks*.
3. = B. flabellata, *J. V. Thompson*.
5.(?) „ fastigiata = B. plumosa, *Pallas*. In S. O. Ridley's paper on the Polyzoa of the 'Alert' Expedition ('Ann. Mag. Nat. Hist.' 1881), the author quotes—
9. B. Murrayana, *var.* fruticosa, *Packard*, as one of the forms of the Arctic circle. Mr. Busk (Polyzoa of the North Polar Expedition, 'Linn. Soc. Jour. Zoology,' vol. xv.) gives the two forms as distinct.
8. „ Murrayana, *Johnst.* (sp.) (*op. cit.* p. 233) = Flabellaria spiralis, *Gray*
„ = Avicella multispina, *Van Ben.*

9. Bugula fruticosa, *Packard* (sp.) (*op. cit.* p. 233)
= B. Murrayana, *var.* fruticosa, *Hincks*
= Menipea fruticosa, *Packard.*
But in a note (p. 233 *op. cit.*) Mr. Busk says: 'Since the above was in type I am more inclined to agree with those who regard *B. fruticosa* as a variety of *B. Murrayana.*'
10. „ uniserialis, *Hincks,* 'Annals,' May 1884, p. 367, pl. xiii. fig. 8. *Loc.*: Victoria, Australia.

At a meeting of the Scientific Society of Christiana, March 1867, D. C. Daniellsen gave an account of two new forms of Polyzoa, which he called *Kinetoskias.* In his notes on a form ('Quart. Jour. Mic. Soc.' vol. xxi. new series) Mr. Busk has made several references to a form closely allied to Bugula (*Kinetoskias, Kor. & Dan.*). Many interesting particulars are given by Mr. Busk in this paper, which the student will do well to refer to. In this Report I will give the results arrived at by the author.

1867. Bugula umbella, *Smitt.*
1873. Naresia cyathus, *Sir C. W. Thomson.*
Bugula Smittii, *Sars.*

Speaking of the genus *Naresia*, Sir C. W. Thomson, several specimens of which are in the Challenger collection—one procured from a depth of 2,650 fathoms—Mr. Busk says: 'The different forms constitute certainly three—and, as I am inclined to think, four—distinct and well-characterised species; but they all agree in certain very peculiar characters, which would seem to be almost, if not quite, sufficient to render the group composed of them of generic value, or at any rate to rank as a distinct sub-genus of *Bugula.* To this genus or sub-genus the appellation bestowed upon it by Koren and Daniellsen obviously has priority over *Naresia.*'

1. Bugula (Kinetoskias) Smittii, *Dan.*
= Kinetoskias Smittii, *Kor. & Dan.*
= Bugula Smittii, *Sars.*
2. „ (Kinetoskias) aborescens, *Dan.*
= K. arborescens, *Kor. & Dan.*
= Bugula umbella, *Smitt.*
3. „ (Kinetoskias) cyathus, *Sir C. W. Thomson*
= Naresia cyathus, *Sir C. W. Thomson*
= K. Smittii, *Kor. & Dan.*
4. „ (Kinetoskias) pocillum, *Busk,* 'Quart. Jour. Mic. Soc.' (*op. cit.*)

In addition to descriptions of all these species Mr. Busk draws attention to the peculiar cell structure, and also gives an elaborate account of the radical tubes or fibres of the same.

In the 'Challenger Report' Mr. Busk modifies the definition of *Bugula* so as to admit the new forms described by him in it.

Zoœcia bi- or multi-serial, closely contiguous and united, arising in continuous series each from the back of the subjacent one. Aperture partial or entire. Avicularia, when present, always on the anterior aspect of the zoœcia.—*Busk*, p. 37.

§ α. Species in which the branches of one part of zoarium are bi-serial, and in another tri- and quadri-serial.

§ β. Species in which the zoœcia are much attenuated downwards. Avicularia supported on long flexible pedicels.

§ γ. Species in which the zoœcia are usually oblong, and little or not at all attenuated downwards. Avicularia shortly pedunculate. Examples: *Bugula* (Bicellaria), *flabellata*, *turbinata*, *avicularia*, *plumosa.*

§ δ. Species in which the zoœcia are wholly unarmed. Examples: *Bugula* (Halophila), *Johnstoniæ*, *Gray.*

§ α. Abyssal forms (?).

1. Bugula versicolor, *Busk*, 'Chal. Rep.' pl. iii. fig. 4.
450 to 350 fathoms.
2. „ leontodon, *Busk*, 'Chal. Rep.' pl. x. fig. 5.
1,525 fathoms.
3. „ sinuosa, *Busk*, 'Chal. Rep.' pl. x. fig. 2.
80 to 150 fathoms.
4. „ mirabilis, *Busk*, 'Chal. Rep.' pl. x. fig. 1.
2,400 fathoms.

§ β.

5. „ reticulata, *Busk*, 'Chal. Rep.' pl. viii. fig. 3.
1,600, 600, 2,160, and 1,325 fathoms.
5.* „ *Var. a*, unicornis, *Busk*, 'Chal. Rep.' pl. ix. fig. 2.
2,500, 1,850, 2,175 fathoms.
6. „ bicornis, *Busk*, 'Chal. Rep.' pl. ix. fig. 1.
1,950 fathoms.

§ γ.

7. „ margaritifera, *Busk*, 'Chal. Rep.' pl. viii. fig. 4.
1,900 to 2,200 fathoms.
8. „ neritina, *Linn.* (sp.) 'Chal. Rep.' p. 42.
9. „ longissima, *Busk*, 'Chal. Rep.' p. xxxi. fig. 7.

Having utilised a previous paper by Mr. Busk on *Kinetoskias*, it only remains for me to give the arrangement of the species in the 'Challenger Report.'

Kinetoskias Smittii, *Kor.* & *Dan.*, 'Chal. Rep.' p. 43. Only referred to in Report.
1. „ cyathus, *Wyv. Thomson*, 'Chal. Rep.' pl. viii. fig. 1 = Naresia, *id. Wyv. Thomson.*
2. „ pocillum, *Busk*, 'Chal. Rep.' pl. viii. fig. 2.

Additional remarks on this genus will be given further on when speaking of a new genus and species instituted by Mr. Hincks.

Genus 19. Ichthyaria, *Busk.*

'Zoarium continuous, branched; branches irregularly dichotomous or forked, biserial, zoœcia facing in one direction; the two series very loosely connected. Zoœcia ventricose, rounded, fork entirely calcified.'—*Challenger Report*, p. 46.

Ichthyaria oculata, *Busk*, 'Chal. Rep.' pl. xiii. fig. 7.

These are the whole of the genera admitted by Mr. Busk in his

'Challenger Report.' Mr. Hincks, however, believing that *Beania* belongs to the *Bicellaria*, rather than to any other group, I place it here out of deference to the author. It is not referred to by Mr. Busk, consequently it does not appear in his synopsis. I have therefore numbered it (20 ?).

Genus (20 ?). Beania, *Johnston.*

'Zoarium sub-corneous or calcareous, erect or decumbent. Zoœcia sessile, erect, scattered, united one to the other by a slender tube, originating from the dorsal surface or from the side near the base; aperture occupying the entire front, the margin furnished with hollow spinous processes arching over the opening; mouth terminal. Oœcia and avicularia wanting.'—*Hincks*, p. 95.

1. Beania mirabilis, *Johnston; Hincks*, p. 96, figs. 8–10, pl. iv. This is the only British species of the genus, and Hincks gives several localities besides the following distribution of this form :—
   Scandinavia; Adriatic; Roscoff.
2. „ australis, *Busk*, 'Brit. Mus. Cat.'
   Patagonia.
3. „ Swainsoni, *Hutton.* (See *Hincks*, 'Brit. Mar. Pol.' p. 96.)
   An erect phytoid form, New Zealand.
4. „ admiranda, *Packard* (*Hincks, op. cit.* p. 96).
   Labrador.

As members of the Bicellariadæ, Mr. Hincks has instituted the two following genera for species found in his Australian collection. It is only fair both to Mr. Busk and to Mr. Hincks to say that in the 'Challenger' collection Mr. Busk has already figured (pl. vi. fig. 1) the Stirparia glabra of Hincks as *Bicellaria stylites*; but as Mr. Hincks's name was published before the issue of the Report the name is changed to that of *B. glabra*, Hincks ('Chal. Rep.'); and in a note Mr. Busk adds, 'Since the above was in type Mr. Hincks has described apparently the same form under the name of *Stirparia glabra*, and gives a full account of the peculiar structure on the zoarium and its stem from better material than those at my command.' I think that Mr. Busk will see that the peculiarities of this remarkable form demand its separation from *Bicellaria* proper, but not from the family in which Mr. Hincks has placed it.

Genus Stirparia, *Goldstein.*

'Zoarium, consisting of erect segmented stems, chitinous or calcareous, and of celluliferous branches, which originate in more or less fabellate tufts close to the summit of the segments. Zoœcia of the normal Bicellarian type, turbinate, somewhat free above; aperture looking more or less upward, turned obliquely inwards, inferior portion of the cells sub-tubular. Avicularia articulated.'—*Hincks*, 'Ann. Mag. Nat. Hist.' vol. xi., ser. 5, p. 195, 1883.

1. Stirparia annulata, *Maplestone*, 'Jour. Micr. Soc. Victoria,' 1870 (type).
2. „ glabra, *Hincks*, 'Ann. Mag. Nat. Hist.' vol. xi. 1883, p. 196, pl. vi. fig. 2
   = Bicellaria glabra, *Busk*, 'Chal. Rep.'

Genus Stolonella, *Hincks.*

Loc.: Geraldton, Western Australia (*Miss Gore*).

The generic description of Mr. Goldstein is revised so that the kindred species, *S. glabra*, may be included.

The following is another peculiar Australian species, for which the generic name is instituted by the author, 'Ann. Mag. Nat. Hist.,' vol. xi. p. 197, 1883.

Zoarium consisting of a creeping stolon, and zoœcia distributed upon it. Stolon chitinous, free in itself, but attached at intervals by adhesive branching discs, which originate from short stolonic offsets, jointed, more or less branched. Zoœcia erect, scattered, always developed close to a joint, attached to the stolon by the pointed lower extremity of the dorsal surface, sub-calcareous, boat-shaped, aperture occupying the whole front, closed in by flattened spinous ribs united together; orifice terminal.

Stolonella clausa, *Hincks* (*op. cit.* p. 198, pl. vii. fig. 6).

Loc.: Creeping over *Fucus*, Geraldton, West Australia (*Miss Gore*).

Mr. Hincks remarks (p. 197, *op. cit.*) 'that the true stoloniferous character of this form seems to call for its separation from *Beania* as represented by our British *B. mirabilis*.'

Family VII. **Notamiidæ**

= Gemellariidæ, *Busk* (part).

'Zoœcia in pairs, each pair arising by tubular prolongations from the pair next but one below it; at each bifurcation a new series of cells intercalated into the branches.'—*Hincks*, 'Brit. Mar. Pol.,' p. 98.

Mr. Hincks says, 'the remarkable structure of the zoarium of *Notamia bursaria* entitles it to stand as the type of a separate family, . . . and the Australian genus *Calwellia* resembles *Notamia* to some extent in the structure of the zoarium.'

In the 'Trans. Microp. Soc. Lond.,' vol. ii. 1849, Mr. Busk gave a somewhat exhaustive account of *Notamia* and its peculiar structural details. In the synopsis which prefaces the description of the Crag Polyzoa, Mr. Busk places *Notamia* as the first genus of his family Gemellariidæ. Only one species described :—

Genus 21. Notamia, *Fleming.*

1. Notamia bursaria, *Linn.*, *Hincks*, p. 100, pl. v. figs. 1–5
= (?) Calwellia bicornis, *W. Thomson.*

Family VIII. **Gemellariidæ,** *Busk*

= Encratiidæ (pars), *Hincks*, 'Brit. Mar. Polyzoa.'

'Zoarium sub-membranaceous, flexible, continuous. Zoœcia opposite, in pairs, unarmed.'—*Busk*, 'Chal. Rep.,' p. 46.

Excepting the genus *Natamia*, which Mr. Hincks takes as the type of his family Notamiidæ, the family Gemellariidæ, *Busk*, includes the same genera as originally arranged under it in the 'Brit. Mus. Cat.,' to which others are added in the 'Challenger Report'; consequently as now arranged the whole appears to be a very natural group.

Genus. Gemellaria, *Savigny.*
„ Didymia, *Busk.*

Genus Dimetopia, *Busk*, 'Brit. Mus. Cat.'
„ Scruparia (pars), *Hincks* (not *Smitt*).
„ ? Brettia, *Dyster*.
„ Huxleya, *Dyster*.

But only species of two genera are described in the 'Challenger Report.'

Genus 22. Gemellaria, *Savigny*.

'Zoarium erect, phytoid. Zoœcia joined back to back; the cells composing the pairs rising one from the top of the other, all the pairs facing the same way. Aperture large, on the front of the cell, slightly oblique. Branches given off from the sides of the cells, close to the upper extremity. No vibracula or avicularia. Oœcia none.'—*Brit. Mar. Polyzoa*, pp. 17, 18.

1. Gemellaria loricata, *Linn.*, Sys. Ed. 10–815; *Hincks*, 'Brit. Mar. Pol.,' p. 18, pl. iii. figs. 1–4.

2 (?). „ Willisii, *Dawson*, coasts of Nova Scotia. This latter form differs from *G. loricata* 'in its narrower and less inflated cells and longer apertures, and in its more dense habit of growth.' I believe with Mr. Hincks that the species 'presents only the character of a variety,' and he places it as a synonym of *G. loricata*.

Genus 23. Didymia, *Busk*.

Didymia, *Busk*, 'Voy. of Rattlesnake,' 'Brit. Mus. Cat.'

'Zoœcia joined side by side, all facing the same way. At a bifurcation each zoœcium of the primary pair giving off a secondary pair. Frontal area almost entirely membranous. Oœcia on a third intermediate zoœcium at a bifurcation.'—*Busk*, 'Chal. Rep.' p. 47.

Didymia simplex, *Busk*, 'Chal. Rep.' p. 47. *Id.*, 'Brit. Mus. Cat.,' *Macgil.*, *Wyville Thom.*

Genus 24. Dimetopia, *Busk*.

'Brit. Mus. Cat.,' 'Voy. of Rattlesnake,' *Macgil.*

'Zoœcia in pairs, apposed back to back; infundibuliform, with a large orifice, each pair facing in a direction at right angles to that of the next; at a bifurcation each of the separate zoœcia gives of a secondary pair.'—*Busk*, 'Chal. Rep.'

1. Dimetopia cornuta, *Busk*, 'Chal. Rep.' p. 47.
2. „ spicata, *Busk*.

Genus 25. Scruparia, *Hincks*.

'Zoarium erect. Branches given off from the back of a cell, and facing in the opposite direction. Zoœcia sub-calcareous, rising one from the other, so as to form a single series, or placed back to back. Aperture small, unarmed, slightly oblique, terminal. Ovicelligerous cells small, and imperfectly developed, placed back to back with the ordinary cells. Oœcia terminal. No avicularia or vibracula.'—*Brit. Mar. Pol.* p. 21.

Scruparia clavata, *Hincks*, 'Brit. Mar. Pol.' p. 24.
'Quart. Jour. Mic. Soc.' pl. xvii. figs. 5–8.

Genus (26 ?). Brettia, *Dyster.*

By some oversight Mr. Busk refers this genus to two different families. See genus 5 of the present Report.

Genus 27. Huxleya, *Dyster.*

'Quart. Jour. Mic. Soc.' vi. p. 260, 1858; *Hincks*, 'Brit. Mar. Polyzoa,' p. 26.

'Zoarium corneous or sub-calcareous, dichotomously branched, the branches given off from the top or side of a cell, and facing in the same direction. Zoœcia uniserial; orifice small, sub-terminal, unarmed.'—*Brit. Mar. Polyzoa*, p. 26.

Huxleya fragilis, *Dyster, Hincks*, 'Brit. Mar. Polyzoa,' pl. ii. fig. 1.

Mr. Hincks has altered the generic character of Dyster. The original description represents the cells as biserial; hence in placing the genus in the *Gemellaridæ* it appears to be out of place. Mr. Hincks places *Huxleya* in his family EUCRATIIDÆ in company with *Brettia.*

Family IX. **Farciminariadæ.**

Id., *Busk*, 'Brit. Mus. Cat.' and 'Challenger Report' only.

'Zoarium sub-membranaceous or corneous, continuous, erect, ramose, radicate. Zoœcia quadri- or multi-serial, disposed round an imaginary axis, and forming cylindrical or prismatic branches.'—*Challenger Rep.*, p. 48.

Only one genus is placed in this family by Mr. Busk in the 'Challenger Report,' but in his remarks on *Farciminaria* he suggests the necessity of establishing two species formerly described as *Farciminaria* ('Quart. Jour. Mic. Soc.' new ser., vol. i. p. 155) in a genus by themselves as *Verrucularia*,[1] V. Suhr,

= Farciminaria, *id.*, *Busk.*
Port Phillip (Australia), *Kirchenpauer.*

Regarded by V. Suhr as a fucus = Verrucularia dichotoma, *V. Suhr*, 'Flora,' 1834, p. 725, tab. i. fig. 9.

Verrucularia Binderi, *Harvey* (?), 'Quart. Jour. Mic. Soc.' vol. i. p. 156, pl. xxxv. figs. 2, 2*a*.

In his original description of the above, Mr. Busk makes the following remarks (*loc. cit.* p. 156):—

'It seems doubtful whether these two species should be referred to our genus *Farciminaria*, but we have thought it better, provisionally at any rate, to place them in it. Should it be thought advisable to separate them from *F. aculeata*, there appears to be no reason against the adoption of V. Suhr's name, *Verrucularia*, notwithstanding his having placed the genus among the Fuci.'

Genus 28. Farciminaria, *Busk.*

Id., *Busk*, 'Brit. Mus. Cat.,' *Kirchenpauer* (pars)? 'Challenger Report,' p. 48.

Zoarium furcate or dichotomous; the angle of each bifurcation

[1] Verrucularia dichotoma (*V. Suhr*), 'Quart. Jour. Mic. Soc.' vol. i. p. 155, pl. xxxv. figs. 1, 1*a*.

occupied by a hollow membranous expansion (modified zoœcium?). Zoœcia oblong, elongated, almost entirely membranous in front, which is depressed or flat, with an acute angular border. Avicularia, when present, sessile or sub-immersed, placed at the bottom in front. Mouth close to the summit, more or less protruded, the oral valve projecting. Oœcia cucullate, superior.

Eight species are described in the 'Challenger Report,' all of which are new, and as these peculiar forms are found generally in deep seas I have given the depth in which each form was taken, the same as in some of the species of the genus *Bugula* in a former part of the present Report.

1. Farciminaria atlantica, *Busk*, 'Chal. Rep.' pl. xxxi. fig. 6. 450–390 fathoms.
2. „ cribraria, *Busk*, 'Chal. Rep.' pl. v. fig. 2. 1,900 fathoms.
3. „ magna, *Busk*, 'Chal. Rep.' pl. v. fig. 1. 1,675 and 2,650 fathoms.
3*a*. „ *Var.* armata, *Busk*, 'Chal. Rep.' pl. xxxi. fig. 1. 1,900 fathoms.
4. „ Brasiliensis, *Busk*, 'Chal. Rep.' pl. xxxi. fig. 2. 400 fathoms.
5. „ Pacifica, *Busk*, 'Chal. Rep.' pl. xxxi. fig. 4. 2,300 fathoms.
6. „ gracilis, *Busk*, 'Chal. Rep.' pl. v. fig. 3. 1,675 fathoms, 32 to 400 fathoms.
7. „ delicatissima, *Busk*, 'Chal. Rep.' pl. xxxi. fig. 5. 1,900, 2,175, 2,400, 1,850, and 1,950 fathoms.
8. „ hexagona, *Busk*, 'Chal. Rep.' pl. xiv. fig. 10, pl. xxxi. fig. 3. 140 to 310, 825, and 1,425 fathoms.

In these *Farciminariæ* very peculiar characters are noted by the author, and the student of both the recent and fossil species of Polyzoa would do well to refer to them.

If we except the two species already placed in the genus *Verrucularia* (V. Suhr) the only species described in the 'Brit. Mus. Cat.' by Mr. Busk is the following, which will make nine species in all:—

9. Farciminaria aculeata, *Busk*, 'Brit. Mus. Cat.'
10 (?). „ uncinata, *Hincks*, 'Ann. Mag. Nat. Hist.' Oct. 1884, p. 277, pl. viii. fig. 2.

This is the Australian species originally described by Mr. Busk, but the *F. atlantica*, *Busk*, No. 1 of the above list, 'strongly resembles' *F. aculeata*. Especially so 'in the aculeate marginal spines being simple, and not furcate, as they mostly are in the Australian species, on the smoothness and comparatively smaller size of oœcium, and in the presence on very many of the zoœcia of a large avicularium.' [1]

[1] Busk, *Chal. Rep.* p. 49.

Group β. FLUSTRINA.

Family X. **Flustridæ**

= Flustridæ, *Busk*, 'Brit. Mus. Cat.'; *Gray* (pars)
= Flustridæ (pars), *D'Orb.*; *Hincks*, 'Brit. Mar. Polyzoa.'
Smitt, 'Krit. Fortech. Scandinav. B.'
= Escharidæ (pars), *Johnst.*, 'Brit. Zoophites.'

Mr Busk in the 'Challenger Report' arranges the genera of this family differently from that of Mr. Hincks in his 'British Marine Polyzoa.'

Genus Flustra, *Linn.*
,, Carbasea, *Gray.*
,, Diachoris, *Busk*, 'Challenger Report.'

Mr. Hincks does not separate the species of *Carbasea*, but includes the whole in the genus *Flustra*, and *Diachoris* he places in a different family.

The following is Mr. Hincks's arrangement in his 'British Marine Polyzoa':—

Family **Flustridæ**

= Escharidæ (pt.), *Johnston*, 'Brit. Zoophites,' *D'Orb.*, 'Pal. Fr.'
= Flustridæ (pt.), *Busk*; Flustridæ, *Smitt.*

'Zoarium corneous and flexible, expanded, foliaceous, erect. Zoœcia contiguous, multiserial. Avicularia usually of a very simple type.'—*Hincks*, p. 113.

Genus Flustra, *Linnæus*

(for F. papyracea)
= Chartella, *Gray*; Carbasea, *Gray*; Semiflustra (sp.), *D'Orbigny.*

'Zoarium erect, frondose. Zoœcia disposed in a single layer, or in two layers, united by the dorsal surfaces, more or less quadrangular or linguiform, with a raised margin, the aperture occupying the whole or a considerable portion of the front of the cell, and closed in by a membranous covering. Oœcia immersed.'—*Hincks*, p. 114.

a. Zoarium in two layers.

1. Flustra foliacea, *Linnæus*, *Hincks*, p. 115, pl. xiv. and xvi.
2. ,, papyracea, *Ell. & Sol.*, *Hincks*, p. 118, pl. xvi. fig. 2.
3. ,, securifrons, *Pallas*, *Hincks*, p. 120, pl. xvi. fig. 3.
,, *Var.* papyracea, *Dalyell.*
4. ,, Barleeii, *Busk*, 'Quart. Jour. Mic. Soc.' 1860, p. 123, pl. xxv. fig. 4; *Hincks*, p. 122, pl. v. figs. 6–8.

b. Zoœcia in a single layer.

5. Flustra Carbasea, *Ell. & Sol.*, *Hincks*, p. 123, pls. xiv. and xvi.
= Carbasea papyracea, *Gray*
= Carbasea, paperea, *Busk*, *Alder*
= Semiflustra carbusea, *D'Orb.*

These are the only British species recorded, described, and figured by Mr. Hincks.

There is something very peculiar about the zoœcia of *F. Barleeii.* The cells are large and rectangular, with an unarmed margin, avicularia oblique. Ovicells in the dry specimens immersed. This is caused by the top wall of the zoœcium, to which the ovicell is attached, being lower than the side walls which support the roofing. The localities of the species are Shetland, in about 50 fathoms; entrance to the Bömmelfjord, in 106 fathoms (*Kirchenpauer*).

In his 'Contributions' Mr. Hincks describes other species of *Flustra.*

6. Flustra dentigera, *Hincks,* Australia, 'Annals,' Feb. 1882, pl. v. fig. 7.
7. " reticulum, *Hincks,* "
   Flustra dissimilis, *Busk,* Bass's Straits.
8. " solida, *Stimpson.* See Note on Hincks's Pol. Barrent's Sea, 'Annals,' Oct. 1880, p. 282, pl. xv. figs. 2, 3.

The following species is a peculiarly northern form, but Mr. Hincks gives it in his Report in the 'Poly. Queen Charlotte Is.'

9. Flustra membranaceo-truncata, *Smitt.*
   Virago Sound, North Sea, and Arctic Seas common.

In the 'Challenger Report' Mr. Busk describes four species of *Flustra,* three of which are new; seven species of *Carbasea,* two of which are new; and five species of *Diachoris.*

§ A. Zoœcia contiguous.

§§ *a.* Utrinque porosæ, *Linn.*

Genus 29. Flustra, *Linn.*

'Zoœcia disposed in two inseparable layers (except when decurrent).' —*Busk,* 'Chal. Rep.' p. 53.

1. Flustra crassa, *Busk,* 'Chal. Rep.' pl. xvi. fig. 6.
   Remarkable, says Mr. Busk, for its thick, almost fleshy consistence.
   The species is only recorded from one station, 149*a.* Kerguelen Island, 28 fath.
2. " denticulata, *Busk,* 'Chal Rep.' pl. xxxii. fig. 2
   = F. denticulata, *var.* inermis, *Busk,* 'Brit. Mus. Cat.'
3. " biseriata, *Busk,* 'Chal. Rep.' pl. xvi. fig. 1.
4. " membraniporides, *Busk,* 'Chal. Rep.' p. xxxii. fig. 7.

Genus 30. Carbasea, *Gray.*

'Zoœcia in a single layer. Front either completely or partially membranous.'—*Chal. Rep.,* p. 55.

1. Carbasea ovoidea, *Busk,* 'Chal. Rep.' pl. xvi. fig. 3, and 'Brit. Mus. Cat.' p. 52, &c.
2. " dissimilis, *Bk.,* 'Chal. Rep.' p. 55
   = C. dissimilis, *Bk.,* 'Brit. Mus. Cat.' p. 51
   = Flustra carbasea, *var. β, Lamk.*
3. " elegans, *Bk.,* 'Chal. Rep.' pl. xvi. fig. 5, and 'Brit. Mus. Cat.' p. 53.
4. " pedunculata, *Bk.,* 'Chal. Rep.' pl. xvi. fig. 4.
5. " Moseleyi, *Bk.,* 'Chal. Rep.' pl, xxxiii. fig. 4. Specimen showing the polypides.

6. Carbasea piciformis, *Busk*, 'Chal. Rep.' p. 57, and 'Brit. Mus. Cat.' p. 50.
7. „ cribriformis, *Busk*, 'Chal. Rep.' pl. xxxiv. fig. 8, and 'Brit. Mus. Cat.' p. 51
= Retepora cornea, *Bk.*, 'Voy. of Rattlesnake,' vol. i. p. 380.

Genus 31. Diachoris, *Busk.*

'Zoarium flexuose, spreading, loosely adnate, or sub-erect and free. Zoœcia flustrine, completely distinct, each connected, with six or more, by tubular processes.'—*Chal. Rep.*, p. 59
= Diachoris, *Busk*, 'Voy. of Rattles.'; 'Brit. Mus. Cat.'; *Heller*; *Macgil.*; *Hutton*
= Mollia (*pars*) *Smitt.* Eschara (*pars*) *Moll.*

1. Diachoris Magellanica, *Bk.*, 'Chal. Rep.' p. 59
= D. Magellanica, *Bk.*, 'Brit. Mus. Cat.'
= D. Buskei, *Heller*, 'Adriatic.'
1[1]. „ „ *Var. a*, distans, *Bk.*, 'Chal. Rep.' pl. xvi. fig. 2.
2. „ crotali, *Bk.*, 'Chal. Rep.' p. 59, and 'Brit. Mus. Cat.'; 'Voy. of Rattles.'; *Macgil.*; 'Nat. Hist. Vic.' Decad. V. p. 32.
3. „ costata, *Bk.*, 'Chal. Rep.' pl. xxxiv. fig. 4.
4. „ inermis, *Bk.*, 'Chal. Rep.' p. 60, and 'Brit. Mus. Cat.' p. 54.
5. „ hirtissima, *Heller*, 'Chal. Rep.' p. 61
= D. hirtissima, *Heller*, 'Adriatic,' p. 94
= Chaunosia, *id.*, *Bk.*, 'Quart. Jour. Mic. Soc.' vol. vii. pl. xxxvi. figs. 12–16.

In addition to this very full record of the genus *Diachoris* from the 'Challenger Report' of Mr. Busk, I think it only fair on my part to give as full a list as possible from all other sources, not only of the genus *Diachoris*, but of *Flustra* and *Carbusea* also.

No true *Diachoris* has yet been recorded as occurring in British Seas, but Mr. Waters in his 'Bay of Nap. Bry.' (*op. cit.* p. 120, Feb. 1879) records three species from this locality.

1. Diachoris patellaria, *Moll.*, 'Ann. Mag. Nat. Hist.' Feb. 1879, pl. x.
= Eschara, *id.*, *Moll.*; Mollia, *id.*, *Smitt*
= Diachoris simplex, *Heller*, 'Bry. Adr.'
2. „ „ *Var.* multijuncta, *Waters*
= Eschara depressa, *Moll.*
3. „ Magellanica, *Busk*, 'Mar. Pol.' p. 54
= D. Buskei, *Heller.*
Mr. Hincks, 'Contrib. to Ann. Mag. Nat. Hist.' Feb. 1881, p. 157, describes a new form from New Zealand.
4. „ bilaminata, *Hincks*, pl. viii. figs. 7, 7a, and the zoarium is composed of two layers of cells placed back to back; the connecting tubes six in number, and very short.
Mr. Waters says the definition of *Diachoris* would

[1] In a note Mr. Busk says that the *D. distans* described by Mr. Hincks from South Africa is quite distinct from the above.

require altering to admit his *D. patellaria*, var. *multijuncta*, . . . and he says that *Diachoris* can only be looked upon as a provisional one; an opinion with which Mr. Hincks 'quite agrees.' But Mr. Hincks says in addition to this that 'the affinity between *Diachoris* and *Beania* and *Bugula* is of the closest kind.' 'Ann. Mag. Nat. Hist.' Feb. 1881, p. 157. The following are the described species:—

5. Diachoris crotali, *Busk*, Bass's Straits.
,, Magellanica, *Busk* = D. Buskei, *Heller*, Straits of Magellan; New Zealand.
,, inermis, *Busk*, same localities.
,, costata, *Busk*, Kerguelen Island.
,, spinigera, *Macgil.*, Australia.
,, hirtissima, *Heller*, Adriatic; Cape of Good Hope = Chaunosia, *id.*, *Busk*.
,, Buskiana, *Hutton*, New Zealand.

In another of his 'Contributions' Mr. Hincks describes other species of this genus ('Ann. Mag. Nat. Hist.' Aug. 1881, pp. 132–134).

,, distans, *Hincks*, *op. cit.* p. 132, pl. v. figs. 4–6, South Africa. Resembles the D. spinigera, *Macgil.*
,, intermedia, *Hincks*, *op. cit.* p. 133, Tasmania.
,, hirtissima, *Heller*.
form. robusta, *Hincks*, *op. cit.* p. 133, pl. v. figs. 9, 9a.

The *Chaunosia fragilis* described by Mr. Ridley (Proc. Zool. Soc. 1881, p. 45), from the Straits of Magellan, 'approaches still more nearly to *Beania*; its polypide, however, is said to be furnished with a gizzard, and it may possibly be entitled to generic rank.'—*Hincks*, *op. cit.* p. 133.

In another paper, 'Polyzoa of New Zealand and Australia,' contributions 'Ann. Mag. Nat. Hist.' March 1885, Mr. Hincks gives a very full account of Diachoris, and describes two new species.

Diachoris elongata, *Hincks*, pl. ix. fig. 1, Napier, New Zealand.
,, quadricornuta, *Hincks*, pl. ix. fig. 2, Australia.

Very many of these Australian forms of Polyzoa, though described by Mr. Hincks, we owe to the laborious scrutiny of Miss E. C. Jelly, whose specimens Mr. Hincks so justly and so continuously acknowledges; Some specimens we owe to Miss Gatty; but for the enthusiastic dredgings of Mr. Bracebridge Wilson, the Port Phillip Head (Victoria) Polyzoa would have been a loss to science.

Mr. Hincks[1] speaking of the genus *Diachoris*, as originally defined by Busk, says that it 'must be regarded as a purely artificial division. But most of the forms which have been ranked under the name present well-marked characters . . . and are properly associated as a natural group. They have the cell of *Bugula* and are furnished with the capitate and articulated avicularium so characteristic of that genus. . . . And probably the natural relationships would be best represented by ranking the true forms of *Diachoris* as a subsection of the genus *Bugula*.' The

[1] *Ann. Mag. Nat. Hist.*, March 1885, p. 246.

disjunct cells is a character which would seem to have but little real significance, for Mr. Hincks says, 'it seems as an occasional condition in species the cells of which are normally continuous, and we have an instance of this in the disjunct form of the well-known *Microporella Malusii.*'

Microporella Malusii, *Audouin*, form disjuncta, *Hincks*, 'Ann. Mag. Nat. Hist.' vol. xv. 5th series, March 1885, p. 249.

Family XI. **Membraniporiidæ**, *Busk*,

'Challenger Report,' p. 61
= Membraniporidæ (pars), 'Brit. Mus. Cat.,' *Smitt* and *Hincks*
= Microporidæ (sp.), *Smitt* and *Hincks*.
For other synonyms, *see* Report.

'Zoarium membranous, membranaceo-calcareous, encrusting and adnate, or erect and free, foliaceous or lobed, then bilaminar or polygono-cylindrical. Zoœcia depressed in front with a raised border, the area filled in by a chitinous membrane, beneath which may be an entire or partial calcified lamina.'—*Chal. Rep.* p. 61.

As this very important group is differently arranged by Mr. Busk in the above Report than by Mr. Hincks in his 'British Marine Polyzoa,' and in his papers, 'Contributions to a General History of the Marine Polyzoa,' I must be pardoned if in this and the following parts of my Report I give as full a digest as possible of the views of the different authors; especially so as Mr. Hincks—and others who adopted his classification—had made considerable advances previous to the publication of the 'Challenger Report.'

The following genera are contained in the 'Challenger' collection, which Mr. Busk arranges as below :—

1. Membranipora, *Blainville*. 2 sections, α and β.
2. Amphiblestrum, *Gray*.
3. Biflustra, *D'Orbigny*.
4. Foveolaria, *Busk*. New genera.
5. Pyripora, *D'Orbigny*. No species in the 'Challenger' collection.

Genus 32. Membranipora, *Blainville*

= Membranipora (pars), *Blainv.*, *Johnst.*, *Auc.*
= Annulipora, Conopeum, Cellepora, Amphiblestrum (sp.), *Gray*
= Cellipora (pars), *D'Orb.*, *Hag.* = Marginaria, *Rœmer.*

'Zoarium encrusting, adnate, calcareous or sub-calcareous; zoœcia quincuncially or serially disposed in transverse rows or irregularly; no internal calcareous lamina; operculum incomplete.'—*Op. cit.* p. 62.

In a note Mr. Busk says that the term *incomplete* is applied to an operculum whose lower border is membranous and more or less ill defined.

The genus *Membranipora*, like the old genus *Lepralia*, has become by the addition of many new species almost unmanageable. Even so as restricted as above. Mr. Busk says the 'genus *Membranipora* includes so many species that it becomes advisable to subdivide it into sections. I am acquainted, either actually or by published descriptions, with between thirty and forty living species, to which no doubt copious additions remain to be made.'

§ *α*. Simplices (no marginal spines).

1. Membranipora albida (?), *Hincks*, pl. xv. fig. 4.
? M. albida, *Hincks*. (*See* following No. 33.)
2. „ crassimarginata, *Hincks*. (No. 30.)
Var. *α*, erecta, *Busk*, 'Chal. Rep.' pl. xiv. fig. 3.
„ *β*, incrustaris, *Busk*, 'Chal. Rep.' pl. xv., fig. 5.
= ? Biflustra Lacroixii, *Smitt*, 'Florid Bryozoa,' pl. ii. p. iv. figs. 85–88.

§ *β*. Spinosæ.

3. Membranipora spinosa, *D'Orb*. 'Voy. en Amér. Mérid.' pl. viii. fig. 1
= M. ciliata, *Macgil*. 'Nat. Hist. Vict.' Decade III.
= M. spinosa, *Busk*, 'Chal. Rep.' p. 64.
4. „ galeata, *Busk*, 'Chal. Rep.' 64; and 'Brit. Mus. Cat.'
Var. *a*, furcata, *Busk*, 'Chal. Rep.' p. 64.
„ *β*, multifida, *Busk*, „ „
„ *γ*, erecta, *Busk*, „ p. 65.

Genus 33. Amphiblestrum, *Gray*.

Type of Genus, *Membranipora Flemingii*.

(See following list, No. 21 to 26.)

'A partial internal calcareous lamina. Aperture more or less trifoliate or obovate.'—*Chal. Rep*. p. 65.

1. Amphiblestrum imbricatum, *Busk*, 'Chal. Rep.' pl. xv. fig. 3.
2. „ cristatum, *Busk*, 'Chal. Rep.' pl. xv. fig. 1.
3. „ papillatum, *Busk*, 'Chal. Rep.' pl. xxxiii. fig. 1.
4. „ cervicorne, *Busk*, 'Chal. Rep.' p. 66
= Membranipora, *id*. 'Brit. Mus. Cat.' p. 60.
5. „ umbonatum, *Busk*, 'Chal. Rep.' p. 66
= Membranipora, *id*. 'Brit. Mus. Cat.' p. 57.
6. „ capense, *Busk*, 'Chal. Rep.' pl. xxiii. fig. 3.

This last species is very doubtfully placed with *Amphiblestrum*.

Genus 34. Biflustra, *D'Orbigny*

= Biflustra, *D'Orb*.; *Busk*, 'Crag Polyzoa,' p. 71. *Manzoni*, *Stolickza*, *Macgil*. (sp.), *Smitt* (pars)
= Flustrellaria (pars), *D'Orb*.

Zoarium dimorphous, encrusting or decurrent, and unilaminar, or foliaceous erect, and bilaminar, readily fissile in all directions. Zoœcia in alternate series, longitudinal or transverse. Zoœcia flustrine, quadrangular or hexagonal (?), with a denticulate lamina at bottom.

Biflustra Savartii, *Audouin*, 'Chal. Rep.' pl. xiv. fig. 2
= Flustra, *id*. *Aud*., 'Ægypte' pl. x. fig. 10
= Membranipora, *id*. *D'Orb*., 'Palæon.'; *Busk*, 'Crag Polyzoa,' p. 31.
= „ corrugata, *Blainv*.
= Biflustra Savartii, *Smitt*, 'Florid. Bry.'

Mr. Busk says of this species that there may be some doubt whether this is really *Flustra Savartii* of Savigny and of the Crag.

Genus 35. Foveolaria, *Busk* ('Chal. Rep.' p. 68).

Zoarium erect, branched and cylindrical, or foliaceous and bilaminar. Front of zoœcia with a thick granular border very deeply imbedded in a pit formed by the thickening of the general ectocyst. A sessile avicularium immediately below or in front of the lower border of the pit.

1. Foveolaria elliptica, *Busk*, 'Chal. Rep.' pl. xxiiii. fig. 5.
2. „ orbicularis, *Busk*, 'Chal. Rep.' pl. xxiii. fig. 4.
3. „ tubigera, *Busk*, 'Chal. Rep.' pl. xiv. fig. 4.
4. „ falcifera, *Busk*, 'Chal. Rep.' pl. xv. fig. 6.

Genus 36. Pyripora, *D'Orbigny.*

Type of genus, *Hippothoa* (Membranipora) *catenularia*, Jameson.

Now that I have given a full list of the whole of the species, in the several divisions of the Membraniporidæ, *Busk* ('Challenger Report'), I do not think that it will be considered at all out of place if I furnish, to the best of my ability, a full list of described forms, details of which will be found in the works of Mr. Busk ('Brit. Mus. Cat.'), Mr. Waters ('Bay of Nap. Bryozoa' and 'Papers on Australian Bryozoa'), Mr. Hincks ('Brit. Mar. Polyzoa'), and Contributions, &c. 'Ann. Mag. Nat. Hist.' Many of the species—thanks to the kindness of Miss E. C. Jelly—are in my cabinet; and even now, from what I know of undescribed species, many remain yet with manuscript names, which will ultimately find their proper place in our lists. For obvious reasons I include no species in the list which have not been fully described.

Family. **Membraniporidæ**, *Hincks.*

'Zoarium calcareous or membrano-calcareous, incrusting. Zoœcia forming an irregular continuous expansion, or in linear series, with raised margins, and more or less membranaceous in front.' — *Brit. Mar. Polyzoa*, p. 126.

Genus. Membranipora, *Blainv.*

'Zoarium incrusting. Zoœcia quincuncial or irregularly disposed, occasionally in linear series; margins raised; front depressed, wholly or in part membranaceous.'—*Brit. Mar. Polyzoa*, p. 128.

a. *With a membranous front wall.*

British Species.

1. Membranipora Lacroixii, *Aud.* (*op. cit.* p. 129, pl. xvii. figs. 5–8).
2. „ Monostachys, *Busk* (*op. cit.* pl. xvii. figs. 3, 4, pl. xviii. figs. 1–4).
3. „ *Var. a*, fossaria, *Hincks.*
4. „ catenularia, *Jameson* (p. 134, pl. xvii. figs. 1, 1*a*, 2).
5. „ pilosa, *Linnæus* (*op. cit.* p. 137, pl. xxiii. figs. 1–4).
6. „ *Var. a*, dentata, *Hincks.*
7. „ *Var. β*, laxa, *Smitt.*
7* „ *Var. γ*, (*Pallas's* sp.)
8. „ membranacea, *Linn.* (*op. cit.* p. 140, pl. xviii. figs. 5–6).
9. „ hexagona, *Busk* (*op. cit.* p. 143, pl. xviii. fig. 7).
10. „ lineata, *Linn.* (*op. cit.* p. 143, pl. xix. figs. 3–6).

11. Membranipora craticula, *Alder* (p. 147, pl. xix. fig. 7).
12. „ spinifera, *Johnston* (p. 149, pl. xix. fig. 1, &c.).
13. „ flustroides, *Hincks* (p. 151, pl. xix. fig. 2).
14. „ discreta, *Hincks* (p. 152, pl. xix. figs. 8, 9).
15. „ curvirostris, *Hincks* (p. 153, pl. xx. figs. 5, 6).
16. „ unicornis, *Fleming* (p. 154, pl. xx. fig. 4).
17. „ Dumerilii, *Aud.* (p. 156, pl. xx. fig. 3).
18. „ solidula, *Alder* and *Hincks* (p. 158, pl. xx. figs. 7, 8).
19. „ aurita, *Hincks* (p. 159, pl. xxi. figs. 5, 6).
20. „ imbellis, *Hincks* (p. 160, pl. xx. figs. 1, 2).

b. *With a calcareous lamina.*

21. Membranipora Flemingii, *Busk* (p. 162, pl. xxi. figs. 1–3).
22. „ cornigera, *Busk* (p. 164, pl. xxi. fig. 4; pl. xxii. fig. 3).
23. „ Rosselii, *Aud.* (p. 166, pl. xxii. fig. 4).
24. „ trifolium, *S. Wood* (p. 167, pl. xxii. figs. 5, 6).
25. „ minax, *Busk* (p. 169, pl. xxii. figs. 2 to 2c).
26. „ nodulosa, *Hincks* (p. 170, pl. xx. fig. 9).

As the whole of the above species are described and figured in the 'Brit. Mar. Polyzoa,' I have not thought it necessary to load my text with the synonymy, range in space and time, and the localities, given so fully by Mr. Hincks. This will be given in tabular form. Some of the species are very widely distributed round our coast, others are more restricted in their range; but as no one would attempt to describe the Polyzoa without consulting this book, I believe the mere name of the species will be a sufficient introduction to future students. From what I have seen of Mr. Shrubsole's specimens, collected from Llandudno, I may say that in this locality the collector may gather a rich harvest of forms. At Hastings, Devon, and Cornwall, both from the shore *débris* and also from deep-sea dredgings, many species may be collected; but as some few of the localities are really classical hunting grounds, I shall consider it to be an advantage, rather than a disadvantage, to give separate lists—without much special details—of these places.

The following appear in Mr. A. W. Waters's papers on the 'Bryozoa of the Bay of Naples,' but I have only numbered those species which are really additions to the British list ('Ann. Mag. Nat. Hist.,' Feb. 1879, pp. 121, 122).

Membranipora pilosa, *Pall.*
„ membranacea, *Linn.*
„ Rosselii, *Aud.*
„ Flemingii, *Busk*, pl. xiii. fig. 2 (see No. 228).
„ *Var.* gregaria, *Heller*, pl. xiii. fig. 5
= M. gregaria, *Heller*, 'Die Bryoz. des Adriatic'
= M. aperta, *Manzoni*, 'Castrocaro.'
27. „ angulosa, *Reuss.*, pl. xiii. fig. 3.

For very full details of fossil species of Membranipora, which range from Recent to Eocene both in Europe and Australia, see the 'Fifth Brit. Assoc. Report on Fossil Polyzoa,' 1884, Montreal (*mihi*), Nos. 42 to 73.

In a series of papers, 'Contributions towards a General History of Marine Polyzoa,' the Rev. Thomas Hincks has described and figured many new forms of *Membranipora* from several localities. Many of these species were collected by Miss E. C. Jelly and Miss Gatty, and submitted to Mr. Hincks for examination. I have only numbered the new forms—or new to present list.

MADEIRA SPECIES.

28. Membranipora tenuirostris, *Hincks*, pl. ix. fig. 3
= M. Flemingii, *Waters*, Bay of Nap. Pol. 'Ann. Mag. Nat. Hist.,' February 1879.
29. " nodulifera, *Hincks*, pl. ix. fig. 2.
30. " crassimarginata, *Hincks*, pl. ix. fig. 1.
31. " granulifera, *Hincks*, pl. ix. fig. 4.
(This species belongs to the *M. Flemingii* group.)
32. " sceletos, *Busk* = Lepralia, *id.*, 'Quart. Jour. Mic. Soc.' 1858. 'Zoophytology,' *Busk*, pl. xx. fig. 3.

From the Contributions towards a General History of the Marine Polyzoa, Rev. T. Hincks, 'Ann. Mag. Nat. Hist.' vol. vi. 1880, pp. 69–91. In the same contribution, Part II., Mr. Hincks describes in full the following species under various divisions (p. 81, &c.) :—

a. *Species with a membranous front wall.*

33. Membranipora albida, *Hincks*, pl. x. fig. 5. *Loc.*: Singapore; on Tubipora musica. Allied to M. curvirostris, *Hincks*.
34. " plana, *Hincks*, pl. xi. fig. 2. *Loc.*: Australia.
35. " armifera, *Hincks*, pl. xi. fig. 5. *Loc.*: Gulf of St. Lawrence; on Flustra membranacea. Allied to M. sophiæ, *Busk*.
36. " horrida, *Hincks*, pl. x. fig. 6. *Loc.*: California.
37. " Carteri, *Hincks*. Australia. Mr. Hincks speaks of this species as having a special interest, 'as being the only known Membranipora which possesses a fully developed bird's head appendage identical in structure with that of the genera *Bugula* and *Bicellaria*.' And in a note he adds that *M. minax*, Sm. (= M. princeps, *Hincks*) is furnished with an avicularia which has the form of the bird's head, but it is fixed. *M. Carteri* has the appendage articulated.
38. " pura, *Hincks*, pl. xi. fig. 3. Australia or New Zealand.
39. " villosa, *Hincks*, pl. x. fig. 8.

a′. *Cell prolonged below the aperture.*

40. Membranipora distorta, *Hincks*, pl. x. fig. 7. *Loc.*: Ceylon. There is evidence of affinity between this interesting form and the common M. pilosa.

b. *With a calcareous lamina.*

41. Membranipora nitens, *Hincks*, pl. xi. fig. 4. Australia; on Polyzoa. 'Certainly distinct,' says Mr. Hincks, 'from the South Atlantic M. tuberculata, *Bosc.*'

42. Membranipora delicatula, *Busk*, pl. xi. fig. 1. Biflustra, *id.*, Crag Polyzoa. ? Biflustra deliculata, *Smitt.* 'Florid. Bry.' (Not. M. deliculata, *Busk.*)
43. " trifolium, *S. Wood. Var.* minor, *Hincks*, pl. xi. fig. 6. *Loc.*: Bahia; on shell.
44. " antiqua, *Busk*, pl. xi. fig. 7. *Busk*, 'Quart. Jour. Mic. Soc.' vol. vi. p. 262, pl. xx. fig. 12.

c. *With a membranous front wall, the orifice surrounded by a border. Operculum with a distinct hinge.*

45. Membranipora mamillaris, *Lamx.*, pl. x. fig. 9. *Loc.*: Australia.
46. " transversa, *Hincks*, pl. xi. fig. 9. Seems to be nearly related to M. Woodsii, *Macgil.*

a. *With a membranous front wall.*[1]

47. Membranipora coronata, *Hincks*, p. 147, pl. x. fig. 1. *Loc.*: Singapore; on coral.
48. " terrifica, *Hincks*, pl. viii. fig. 5. *Loc.*: Straits of Magellan; on Eschara flabellaris, *Busk.*
49. " rubida, *Hincks*, pl. viii. fig. 6. *Loc.*: Australia; on stone.
50. " bicolor, *Hincks*, p. 148, pl. ix. fig. 1. *Loc.*: West Australia.
51. " bellula, *Hincks*, p. 149, pl. viii. figs. 4, 4*a*, 4*b*.
51*a*. " " *Var.* α, bicornis.
51*b*. " " " β, multicornis. *Loc.*: Normal and var. β, Australia, Ceylon; *var.* α, Madagascar, St. Vincent, Cape Verd Islands.

b. *With a calcareous lamina.*

52. Membranipora patula, *Hincks*, p. 150, pl. ix. fig. 4. *Loc.*: California.
53. " setigera, *Hincks*, pl. viii. fig. 3. *Loc.*: Australia, investing Serpula. M. setigera belongs to the same section of the genus as our own British species, M. Rosselii and M. trifolium.
54. " spinosa, *Quoy* and *Gaimard*.
= flustra, *id.*, *Quoy* and *Gaimard*, 'Voy. de l'Astrolobe.'
= M. ciliata, *Macgil*, Transac.
= M. spinosa, *Busk*, 'Polyzoa of Kerguelen Island.' D'Orb. describes a species of M. spinosa ('Voy. dans l'Amér.') which bears a close resemblance to M. spinifera, *Johnst.* *Loc.*: Kerguelen Island; Australia; Arabian Sea, between Bombay and Aden.
55. " permunita, *Hincks*, p. 151, pl. x. fig. 2. *Loc.*: Off Curtis Island, Bass's Straits.
56. " denticulata, *Macgil.* pl. viii. fig. 2
= Caleschara, *id.*, 'Prod. Zool. Vict.'

[1] Continuation of Papers by Mr. Hincks, *Ann. Mag. Nat. Hist.*, Feb. 1881.

57. Membranipora cervicornis, *Busk*, pl. viii. fig. 1, pl. x. fig. 3. Mr. Hincks (pp. 153, 154) gives several interesting particulars of this form.

In Captain Warren's collection of Polyzoa, in the possession of the Free Museum, Liverpool, Mr. Hincks gives additional particulars of new Membranipora ('Ann. Mag. Nat. Hist.,' July 1881).

58. Membranipora pyrula, *Hincks*, pl. i. fig. 2, p. 3 = M. lineata, *Macgil.*, 'Prod. Zool. Victoria.' *Loc.*: Bass's Straits.
59. „ inarmata, *Hincks*, pl. iv. fig. 4.
53. „ vitrea, *Hincks*, pl. i. fig. 1. *Loc.*: Curtis Island.
54. „ punctigera, *Hincks*, pl. i. fig. . *Loc.*: Curtis Island; on *Retepora.*
55. „ radicifera, *Hincks*, pl. ii. figs. 6, 6*a*.
56. „ inornata, *Hincks*, pl. iv. fig. 5. *Loc.*: Bass's Straits.
57. „ roborata, *Hincks*, pl. ii. fig. 3. [This species seems to occupy a somewhat intermediate place between *Flustra* and *Membranipora.*] *Loc.*: Off Curtis Island.

In another paper ('Ann. Mag. Nat. Hist.,' August 1881) Mr. Hincks describes the following species:—

58. Membranipora amplectens, *Hincks*, pl. iii. fig. 7. *Loc.*: Australia. Species allied to *M. pilosa*, but differs from it in many points.
59. „ vetata, *Hincks*, pl. v. fig. 3.
60. „ circumclathrata, *Hincks* (*op. cit.*), p. 131, pl. v. fig. 1.
61. „ variegata, *Hincks* (*op. cit.*), pl. v. fig. 2. *Loc.*: Santa Cruz, California; Nos. 59–61.
„ pilosa, *Linn.* Form, multispinata, *Hincks*, 'Annals,' Feb. 1882, pl. v. fig. 6.

In the 'Annals,' November 1880, vol. vi. 5th series, five species are described:—

Membranipora tenella, *Hincks* (*op. cit.*), p. 376, pl. xvi. fig. 7. *Loc.*: Florida; on weed.
„ Flemingii, *Busk.*
Var. (*op. cit.*) p. 376, pl. xvi. fig. 8. A spineless form of Busk's species.
„ pedunculata, *Manzoni*, pl. xvii. figs. 2, 2*a*. *Loc.*: Ceylon; on weed.
„ polita, *Hincks* (*op. cit.*), pl. xvii. fig. 1. *Loc.*: Glenelg., Australia.
„ corbula, *Hincks* (*op. cit.*), p. 378, pl. xvii. fig. 6. *Loc.*: Australia.

Polyzoa of India, coast of Burmah, Contributions, *Hincks*, 'Annals,' May 1884, p. 257.

Membranipora favus, *Hincks* (*op. cit.*), pl. xiii. fig. 3.
„ marginella, *Hincks* (*op. cit.*), pl. xiii. fig. 1.

In his Report on the Polyzoa of Queen Charlotte Island, 'Geological and Natural Hist. Survey of Canada' (=Papers in 'Annals,' December 1882, June 1883, January 1884, March 1884), Mr. Hincks gives very elaborate details of the following species :—

Membranipora variegata, *Hincks*, Queen Charlotte Island; California. 'Specimens occur in which there are two of the pedicellate avicularia at opposite sides of the cell instead of the normal one.'

" acifera, *Macgil.* Form, multispinata, *Hincks*, 'Annals,' Dec. 1882, pl. xix. fig. 4. *Loc.*: Virago Sound, Victoria, *Macgil.*

" echinus, *Hincks* (*op. cit.*), pl. xix. fig. 5 (p. 8 of Report). *Loc.*: Houston Stewart Chan.; Cumshewa, 20 fathoms.

" exilis, *Hincks* (*op. cit.*), pl. xx. fig. 1. *Loc.*: Houston Stewart Chan.

" Sophiæ, *Busk.* Form, matura, *Hincks* (*op. cit.*), pl. xx. fig. 2. 'Described as *M. conferta* ('Annals' for September 1882). I am now convinced that it is a form of *M. sophiæ*. Smitt notices intermediate varieties.'—*Hincks*. *Loc.*: Houston Stewart Chan., Spitzbergen.

" nigrans, *Hincks* (*op. cit.*), pl. xix. figs. 2, 2*a*. *Loc.*: Houston Stewart Chan.; Virago Sound.

" levata, *Hincks* (*op. cit.*), pl. xix. figs. 6, 6*a*. *Loc.*: Houston Stewart Chan.; Cumshewa.

" protecta, *Hincks* (*op. cit.*), pl. xix. fig. 3. *Loc.*: Virago Sound; Cumshewa. 'Other species,' says Mr. Hincks, 'armed with more or less branching spines' are—

" cornigera, *Busk*, Shetland.

" bellula, *Hincks*, Australia.

" cervicornis, *Busk*, Victoria.

" cervicornis, *Haswell*, Queensland.

Haswell's name cannot be retained, having been previously employed by Busk. I venture to suggest the following as a substitute for it.—*Hincks.*

" Haswellii, *Hincks.*
= M. cervicornis, *Haswell.*

" corniculifera, *Hincks*, 'Annals,' December 1882, pl. xx. figs. 4, 4*a*. *Loc.*: Cumshewa.

" minuscula, *Hincks* (*op. cit.*), pl. xx. figs. 3, 3*a*.

" membranacea, *Linn.* Form, serrata, *Hincks*. *Loc.*: Virago Sound.

" pallida, *Hincks*, 'Annals,' Appendix, March 1884. 'Annals' and 'Mag. Nat. History,' vol. xv., *Hincks*, Contributions, &c. vol. xv., March 1885.

" valdemunita, *Hincks* (*op. cit.*), pl. vii. fig. 2. *Loc.*: Napier, New Zealand.

" hians, *Hincks* (*op. cit.*), pl. vii. fig. 5. *Loc.*: New Zealand.

" acuta, *Hincks* (*op. cit.*), pl. vii. fig. 6. *Loc.*: New Zealand.

Membranipora perfragilis, *Macgil.* = Biflustra, *id.*, 'Nat. Hist. of Victoria,' Decade VI. p. 27. Figure of Avicularia, and description given by *Hincks*, 'Annals,' October 1884, pl. vii. fig. 4. *Loc.*: Victoria, Australia.

In the description of New Polyzoa collected by J. Y. Johnson, of Madeira, in the years 1859 and 1860, as Mr. George Busk gave the first list of *Membranipora* in the 'Quart. Jour. Mic. Soc.' 1858, 1860, 1861, it would be indiscreet on my part not to give it, together with the original references.

Membranipora tuberculata, *Bosc.*, pl. xviii. fig. 4, formerly confounded with *M. membranacea* (see *ante*, 41).
" trichophora, *Busk*, pl. xviii. fig. 2.
" antiqua, *Busk*, pl. xx. figs. 1, 2 (No. 44).
" Rosselii, *Aud.* (see No. 23).
" Lacroixii, *Aud.* (see No. 1).
" lineata, *Linn.* (see No. 10).
" calpensis.

For details of Recent Scandinavian Membranipora and Synonyms, see 'Fifth Report on Fossil Polyzoa,' Brit. Assoc. 1884, where I have given a full list of Smitt's identifications. Part II. Historical Labours, p. 58 of Report. No. 19 to No. 28.

Genus 37 (?). Megapora, *Hincks.*

'Ann. Mag. Nat. Hist.' 1877; 'Brit. Mar. Polyzoa,' p. 171.

'Zoarium encrusting. Zoœcia, with a depressed area in front, surrounded by a raised margin, and partially closed in by a calcareous lamina; aperture trifoliate, the lower portion filled in by a horny plate on which the opercular valve works.'—*Brit. Mar. Pol.* p. 171.

Megapora ringens, *Busk*, 'Brit. Mar. Pol.' p. 172, pl. xxii. fig. 1 = Lepralia ringens, *Busk*, 'Quart. Jour. Mic. Soc.' 1856, p. 308, pt. 308, pl. ix. figs. 3–5; *Norman*, Shetland Polyzoa, 'Brit. Assoc. Rep.' 1868, p. 307.

This is a deep-water form, and the localities and geographical distribution very limited. *Loc.*: Shetland, 80–170 fathoms; Bergen.

Membraniporidæ, *Hincks.*

Genus Siphonoporella, *Hincks.*

'Ann. Mag. Nat. Hist.' Contributions, July 1880.

'Zoœcia with raised margins, front depressed, in part membranaceous, a small calcareous tube with wide mouth placed at one side of the lamina, below the aperture, and opening into the cavity of the cell. Zoarium in only known species encrusting.'—*Hincks.*

Siphonella nodosa, *Hincks, op. cit.* pl. xi. fig. 10.

Genus Euthyris, *Hincks.*

'Ann. Mag. Nat. Hist.' vol. x. 5th ser. 1882.

? THAIROPORA, *Macgil.* 'Trans. Roy. Soc. Victoria,' Dec. 1881.

Zoarium corneous, erect and foliaceous. Zoœcia with raised margins, aperture closed by a membranaceous (or membrano-calcareous) wall;

orifice surrounded by a chitinous border; oral valves furnished with a distinct fringe.

Euthyris obtecta, *Hincks* (*op. cit.* pl. vii. fig. 3). *Loc.*: Australia.

Macgillivray recently constituted a genus under the name THAIROPORA, *Macgil.*, for a parallel group amongst the *Membraniporidæ*, and Mr. Hincks says, 'we must recognise here the characters of a generic group, in which Carbasea episcopalis, *Busk*, and C. bombycinna, *Ellis & Solander*, will rank, as well as the species E. obtecta, *Hincks*.' As a set off against this it will be seen that Mr. Busk—'Challenger Report'—places these species in new divisions.

Family XII. **Microporidæ**, *Busk*

= 'Challenger Report,' p. 70
= Microporidæ (pars), *Smitt*, *Hincks*
= Membranipora (pars), *Authors.*

'The much depressed front of the zoœcia beneath the chitinous epitheca, wholly occupied, except at the summit, by a strong calcareous lamina, usually perforated or fissured on the sides, and sometimes forming a transverse diaphragm, which divides the cavity of the zoœcium into two chambers.'—*Op. cit.* p. 70.

1. Genus Micropora, *Gray.*
2. ,, Vincularia, *Defrance.*
3. ,, Steganoporella, *Smitt.*
4. ,, Caleschara, *Macgillivray.*
5. ,, Diplopora, *Macgillivray.*
6. ,, Setosella, *Hincks.*

Genus 38. Micropora, *Gray*

= Membranipora (pars), 'Brit. Mus. Catalogue'
= Lepralia (sp.), *Norman*; Steganoporella (sp.), *Hincks*
= Repteschareilina (pars), *D'Orb.*

'Zoarium incrusting. Zoœcia with an internal calcareous lamina occupying the entire area, with a perforation at each upper angle below the orifice, which is apical, with a continuous calcareous peristome.'—*Chal. Rep.* p. 70.

1. Micropora uncifera, *Busk*, 'Chal. Rep.' pl. xv. fig. 7.
2. ,, coriacea, *Esper*, 'Chal. Rep.' p. 71.
These are the only two species of this genus in the 'Challenger' collection.

In his 'British Marine Polyzoa,' Mr. Hincks describes two species only.

Micropora coriacea, *Esper*, *op. cit.* p. 174, pl. xxiii. figs. 5–7.
3. ,, complanata, *Norman*, *op. cit.* pl. xxiii. figs. 8, 9
= Lepralia, *id.*, 'Ann. Nat. Hist.' 1864 (*Norman*)
= Membranipora, *Smitt*, *Manzoni.*

M. coriacea, *var. Hincks*, 'Polyzoa Bass's Straits.' 'Avicularia are more freely developed than in British specimens.'

4. Micropora elongata, *Hincks* = Steganoporella, *id.*, *Hincks*, Africa.
5. ,, Jervoisii, *Hincks*=Steganoporella, *id.*, *Hincks*, Australia, 'Annals,' Nov. 1880, pl. xvi. figs. 4, 5.

Genus 39. Vincularia, *Defrance.*

See 'Challenger Report,' p. 71.

'Zoarium erect, continuous, branched or simple; radicate or fixed. Sub-cylindrical or polygonal. Zoœcia disposed in alternate longitudinal series. Frontal area quadrangular, oblong, arched above, in the natural state filled in by a chitinous epitheca, in which is seated the oral orifice. Beneath the epitheca a calcareous lamina occupying the lower two thirds of the area, and terminating above in a free border, from which a median process arises, which joining above a process from each side of the zoœcia on a level with the lower border of the orifice forms with those processes a transverse ridge, with an arch on each side of the median process. Opercula incomplete below, composed of a thickish membrane supported on the inner face by a strong chitinous bow having a projecting process near each lower angle for the attachment of the occlusor muscles. Oœcia represented by a small chamber in the upper part of the cell, which opens above the oral orifice.'—*Chal. Rep.* p. 72.

It is very evident that following the above clear definition of what Mr. Busk considers as the true probable limit of *Vincularia*, Defrance, many ill-defined fossil species must fall out of the list. Although only proposed provisionally, *Vincularia*, thus defined, have very many natural characters for its recommendation; but still many points in the structure of some of the species have been discussed by Mr. A. W. Waters; by Mr. Hincks, in 'Ann. Mag. Nat. Hist.' 5th ser. vol. ix. 1882, p. 119; and now by Mr. Busk in the 'Challenger Report.' I have already discussed the fossil species in my last Brit. Assoc. Rep., Fam. VII. Cellariidæ, and all that I am prepared to do now is to catalogue the species described by authors in their various papers. But it seems to me that if we retain the genus *Vincularia*, it ought to be mentioned by future authors as to whether they accept the genus as defined by Mr. Busk in the 'Challenger Report,' or record their species on the basis of the ill-defined generic characters of previous authors.

In the 'Challenger Report' Mr. Busk has given good woodcut illustrations (pp. 72, 73) of the chitinous arch of two of the species described.

1. Vincularia gothica, *D'Orb.* 'Chal. Rep.' pl. xxiii. fig. 1.
   Vincularia id., 'Palæon. France,' p. 68
   = ,, Novæ-Hollandiæ, *Haswell*
   = ,, steganoporoides, *Macgil.*, New Sp. Bry.
2. ,, gothica, *var.* granulata, *Busk*, 'Chal. Rep.' p. 73.
3. ,, labiata, *Busk*, 'Chal. Rep.' p. 73.

In the 'Brit. Mus. Cat.' Mr. Busk described two species—

Vincularia ornata.
,, Neo-Zelanica (see *Steganoporella*).

Mr. Busk remarks of *V. steganoporoides*, Macgil. (No. 1), that it is regarded by Mr. Hincks ('Gen. Hist. Mar. Pol.,' 'Ann. Mag. Nat. Hist.' 5th ser. vol. ix. p. 119) as a form of his *Steganoporella Smittii* ('Brit. Mar. Pol.' p. 178), which, however, I should myself refer to the genus

Micropora. It is clearly quite distinct from Mr. Macgillivray's species ('Chal. Rep.' p. 72, note 2).

Genus 40. Steganoporella, *Smitt.*

Florid. Bryozoa

= Steganoporella, *Hincks*, 'Brit. Mar. Pol.'; *Waters*; *Macgil.*
= Vincularia (sp.), *D'Orb.*

'Zoarium polymorphous; erect and branched, or lobate or decumbent, and foliaceous and crustaceous. Zoœcia oblong and arched above. Frontal area occupied by a delicate chitinous membrane, which is closely adnate to the internal calcareous lamina for about the lower half of the area; above free, and supporting the operculum, and having on each side below the orifice a minute forked or irregularly branched vertical chitinous rod. Opercula large, semicircular, usually of two kinds, the membranous portion supported by a branching chitinous framework. A strong internal calcareous lamina, which, about the middle of the length of the cell, bends backward to the posterior wall, forming a transverse diaphragm, by which the cell is divided into two distinct chambers, communicating with a phrenic opening through which the polypide is protruded, supported on or passing over a large hollow process rising from the upper and anterior part of the transverse diaphragm.'—*Chal. Rep.* p. 74.

1. Steganoporella magnilabris, *Busk*, 'Chal. Rep.' p. xxiii. fig. 2, and woodcuts, p. 76
 = Membranipora, *id.*, 'Brit. Mus. Cat.'
 = Steganoporella elegans, *Smitt*, Flor. Bry.
 = ,, magnilabris, *Hincks*; *Waters*; *Macgil.*
 = (?) Biflustra crassa, *Haswell*
 = Steganoporella Neo-Zelanica (sp.), *Waters.*
2. ,, Neo-Zelanica, *Busk.* Referred to 'Chal. Rep.' pp. 74 and 76
 = Vincularia Neo-Zelanica, *Busk*, 'Brit. Mus. Cat.'
3. ,, Smittii, *Hincks*, 'Brit. Mar. Pol.' p. 178. See note in this Report on *Vincularia gothica (ante).*

Family Steganoporellidæ, *Hincks.*

'Ann. Mag. Nat. Hist.,' May 1884.

Mr. Hincks, in one of his contributions ('Annals,' May 1884, 5th ser. vol. xiii. p. 358), says Smitt places the genus *Steganoporella* 'among the Microporidæ, and I have given it the same position in my history of the British Marine Polyzoa. But I am now inclined to agree with Dr. J. Jullien[1] so far as to regard the dithalamic condition of the zoœcium which distinguishes it as entitling it to rank in a separate *family* group. It is only right, however, that the name of the group should be taken from Smitt's genus *Steganoporella*, which is founded on the division of the

[1] 'Note sur une nouvelle division des Bryozoaires Cheilostomiens.' *Bull. de la Soc. Zool. de France*, t. vi. 1881.

zoœcium into an upper and lower chamber by the interposition of a calcareous lamina beneath the membranous front wall.' But Mr. Hincks says that he is unable to follow Dr. Jullien in his proposed distribution of the Cheilostomata into two principal groups, characterised by the presence or absence of this double ectocyst. . . . There is room, however, for a fuller investigation of its history and meaning.

After duly considering the question raised by Dr. Jullien, Mr. Hincks believes that there are at least two distinct generic types—there may be more—and these are represented by the species given below:—

Genus. Steganoporella.

Steganoporella magnilabris, *Busk* (see *ante*).

Genus. Smittipora, *J. Jullien.*

Smittipora abyssicola, *Smitt.*

I at one time referred the above species to *Setosella* (*mihi*), but the British species (*S. vulnerata*), for which this genus was founded, does not possess the dithalamic cell.

Two species, formerly described as *Steganoporella*, are now referred to *Micropora.*

Genus 41. Caleschara Macgillivray.

(See *Busk*, 'Chal. Rep.' p. 76.)

'Zoarium polymorphous; erect, foliaceous, and contorted, or composed of ligulate branches and bilaminar, or decurrent and incrusting. Zoœcial area pyriform; the margin very thick and bevelled off to a considerable depth, so as to leave a very contracted elliptical aperture, at first membranous, but eventually occupied in the lower two-thirds by a calcareous lamina attached below to the bottom of the aperture, and above by a broad band on each side, and leaving on either side an elongated fissure. The upper third above the lamina represents the internal or secondary orifice. In the natural state the entire area is filled in by a rather thick epithecal membrane, in which alone is seated the semicircular or subcrescentic operculum. Fertile cells distinguished by their greater width.' —*Chal. Rep.* pp. 76 and 77.

Caleschara denticulata (?) *var.* tenuis, *Busk.*
'Chal. Rep.' p. xxi. fig. 9.
See *Hincks*, 'Ann. Mag. Nat. Hist.' Feb. 1881, p. 152, pl. viii. fig. 2.

Genus 42. Diplopora, *Macgillivray.*

'Zoarium incrusting; cells occupied by a calcareous membrane in front, and divided into two parts, the posterior half being very much elevated; a narrow transverse portion a little distance behind the mouth, and in front of the elevated part, deficient in calcareous matter and entirely membranous.'—*Macgillivray*, Proceed. Roy. Soc. Victoria. Diplopora cincta (Hutton's sp.). *Loc.*: Queenscliffe; Portland (*Mapleston*).

This is the Membranipora cincta of Hutton, and is the same species that has been described as *Membranipora transversa* by Mr. Hincks.

Genus 43. Setosella, *Hincks*, 'Brit. Mar. Pol.' p. 180
= Membranipora (pt.), *Busk*
= Cupularia (part), *Smitt*, 'Florid. Bryoz.' ii. 14
= Setosella, *Hincks*, 'Ann. Mag. Nat. Hist.' 1877
= Setosella. Referred to only 'Chal. Rep.' p. 70.

'Zoarium incrusting. Zoœcia with raised margins; front depressed and wholly calcareous; aperture semicircular. Vibracular cells alternating with the zoœcia throughout the colony. Vibraculum slender and setiform.'—*Op. cit.* p. 180.

Setosella vulnerata, *Busk* ('Brit. Mar. Pol.' p. 181, pl. xxi. fig. 7)
= Membranipora id., *Busk*, 'Quart. Jour. Mic. Soc.' viii. pl. xxv. fig. 3, *Norman.*
" Shetland dredgings, 'Brit. Assoc. Rep.' 1867, p. 305
= Setosella vulnerata, *Hincks* ('Ann. Mag. Nat. Hist.' 1877).

Family XIII. **Electrinidæ**, *Busk*

= Electrinidæ, *D'Orb.*, 1851, 'Palæon. France,' p. 329
= Membraniporidæ (pars), *Auctt.*

'Zoarium erect or incrusting, more or less flexible or sub-testaceous. Zoœcia turbinate or sub-turbinate. Wall punctured. A wide expanding aperture, the border toothed or furnished with chitinous or aculeate spines. One or more chitinous spines, of larger size than the rest, articulated on the front of the zoœcium below the aperture, or an articulated avicularian process in the same situation. Oœcia when present galeate.'—*Chal. Rep.* p. 78.

Genus 44. Electra, *Lamouroux.*

Character: That of the family.

This family seems to be founded upon two well-known types of Polyzoa: the not too well-known *Electra verticillata* (Lamx.), and the well known and widely distributed *Electra* (Membranipora) *pilosa* (Linn.).

In his 'Brit. Mar. Pol.' (p. 137) Mr. Hincks places the *M. pilosa* with the group having a membranous front wall, but he does not make any remarks upon the species as being probably taken as the type of any new family, although from the very full list of synonyms furnished by him a doubt as to its future location may have arisen in his mind. Three varieties are described in the 'Brit. Mar. Pol.' which will be mentioned in their proper place. In the 'Chal. Rep.' only one new species is described, but Mr. Busk suggests that perhaps four or five described forms may be included in the genus, as here defined.

1. Electra cylindrica, *Busk*, 'Chal. Rep.,' pl. xxxiii. fig. 2, not *E. cylindrica*, *D'Orb.*
2. " pilosa, *Linn.* (see 'Brit. Mar. Pol.' p. 137).
   Var. α, dentata, *Hincks* (*op. cit.* p. 137).
   " *β*, laxa, *Smitt* (*op. cit.* p. 137).
   " *γ*, *Pallas* (*op. cit.* p. 138).
3. " verticillata, *Lamx.*, 'Flexible Coralines.'
4. " triacantha, *Lamx.*
5. " bellula, *Hincks.*
6. " (?) distorta, *Hincks.*

The original description of Lamouroux (' Flex. Coral.') may be given here:—

' Electra.

' " Flex. Coral," ed. 1824, translated, p. 53.

' Polypidoms branching; cells campanulated, ciliated on their border, and verticillated. . . . The electra is very common in the European seas; when the polypi are alive their colour is a red violet of greater or less brilliancy; but when exposed to air and light it becomes an earthy white.' —' Electra verticillata,' *Lamouroux, op. cit.* pl. 2, figs. a, b, 2.

Group C. Escharina, *Busk.* ' Challenger Rep.' p. 79.

Family XIV. **Bifaxariadæ,** *Busk.*

' Zoarium rigid, continuous or articulated, biserial, variously branched. Zoœcia alternate, closely connate back to back and facing in opposite directions.'—*Chal. Rep.* p. 79.

Genus. Bifaxaria, *Busk.* Genus. Calymmophora, *Busk.*

Genus 45. Bifaxaria, *Busk.*

' Zoarium continuous or segmented, variously branched, rooted by radicle tubes. Zoœcia biserial, alternate, facing bifariously on the two sides, very closely contiguous. Orifice elliptical from side to side, or semi-orbicular or sub-orbicular. Peristome sometimes sub-tubular, sometimes deeply immersed. A small circular immersed avicularium on each side of the orifice, sometimes wanting, or replaced by a short hollow spinous process. Oœcia, when present, deeply imbedded in the superjacent zoœcium. A raised ridge or keel on the middle of the front, the upper pointed termination of which constitutes a more or less prominent mucro in front of the orifice.'—*Chal. Rep.* pp. 79, 80.

§ a. Articulatæ.

1. Bifaxaria submucronata, *Busk*, ' Chal. Rep.' pl. xiii. fig. 1.
2. „ lævis, *Busk.* ' Chal. Rep.' pl. xiii. fig. 2
   = Antipathis humilis, *Agassiz* and *Pourtalès.*

§ β. Inarticulatæ.

3. „ corrugata, *Busk*, ' Chal. Rep.' pl. xiii. fig. 3; and pl. xxiv. fig. 6.
4. „ papillata, *Busk*, ' Chal. Rep.' pl. xiii. fig. 4; and pl. xxiv. fig. 4.
5. „ minuta, *Busk*, ' Chal. Rep.' pl. xiii. fig 5.
6. „ reticulata, *Busk*, ' Chal. Rep.' pl. xiii. figs. 6 and 8.
7. „ abyssicola, *Busk*, ' Chal. Rep.' pl. xxiv. fig. 5.
8. „ denticulata, *Busk*, ' Chal. Rep.' pl. xxiv. fig. 3.

Genus 46. Calymmophora, *Busk.*

' Zoarium continuous, irregularly branched; biserial; the zoœcia alternate, placed back to back facing in opposite directions, pyriform, squarely truncated at the top, with a hollow conical process at each angle, often supporting a small avicularium. Orifice large, orbicular, with a wide notch in front, terminal (looking directly upwards). Oral valve semicircular, curved transversely, with numerous perforations. Wall

exceedingly delicate, with a very slender median and two lateral ridges, and a row of very distant pores on each side, and a few of smaller size on the sides and below the orifice. Oœcia galeriform, completely immersed in front of the superjacent zoœcium, and covered with the general epithecal membrane with which the entire growth is enveloped as in a loose veil.' —*Busk*, 'Chal. Rep.' pp. 82, 83.

Calymmophora lucida, *Busk*, *op. cit.* pl. xxxii. fig. 3.

The only species of the genus, and obtained from station 163*a*. Twofold Bay, 150 fathoms.

Family XV. **Salicornariadæ**, *Busk*, 'Chal. Rep.'
'Brit. Mus. Cat.' (pars), 'Crag Polyzoa,' (pars)
= Cellariidæ, *Hincks*, 'Brit. Mar. Polyzoa.'

'Zoarium erect, radicate or fixed; simple, branched or lobed; segmented or continuous; cylindrical, with the cells disposed round an imaginary axis, or compressed and bilaminar; surface areolated. Zoœcia completely immersed, each corresponding to an area; front depressed, usually concave. Orifice crescentic, semicircular, or elliptical. Oœcia inconspicuous, opening at or near the summit of the area above the orifice. In the decalcified condition the interareolar septa exhibit a delicate chitinous, probably tubular, filament, apparently continuous throughout the segment; and on each side of the oral orifice a slender curved chitinous rod or trabecula, which sometimes unite so as to form a complete or incomplete ring. Avicularia usually present, either vicarious or intercalated.'—*Chal. Rep.* p. 84.

As CELLARIIDÆ, *Hincks*, I gave a tolerably fair account of this family group in my fifth British Report on Fossil Polyzoa. In that Report I dealt, as a matter of course, with fossil species only, which appeared to me to be rather more abundant than recent forms. It may now, in justice to the respective authors, be as well to allude to the classification of Mr. Hincks before passing on to the 'Challenger Report.'

In 1879 ('Ann. Mag. Nat. Hist.') Mr. Waters gave only a single species in his 'Bay of Naples Bryozoa.' The genus, says Mr. Hincks, 'possesses a very cosmopolitan representative in our own *C. fistulosa*,' and although *Cellariæ* are widely distributed, the foreign specimens differ but slightly from British forms, if a large number of cells are studied and compared. In the fifth Report I gave conclusions arrived at by Mr. Waters after a careful study of a large series of specimens collected from several localities. In dredgings in the Bay of Naples a vast quantity of fragmentary specimens of *C. fistulosa*, Linn., may be obtained, and the careful study of these in association with the British forms will afford a large amount of practical details of species when dealing with British and foreign species. The brief description of the family group, as given by Mr. Hincks, is markedly conspicuous when compared with the fuller description of Mr. Busk.

'Zoarium usually rhomboidal or hexangular, disposed in series round an imaginary axis, so as to form cylindrical shoots. Zoarium erect, calcareous, dichotomously branched.'—*Hincks*, p. 103.

As, however, only three species are described as British, it may be well to give these first, and then refer the student to the 'British Marine Polyzoa,' for very full details.

Cellariidæ, *Hincks*, 'Brit. Mar. Polyzoa'; *A. W. Waters*, Bryozoa, Bay of Naples; Papers on Australian Bryozoa (fifth Report 'Brit. Assoc.' 1884 on Fossil Polyzoa), &c.

Genus Cellaria, *Lamouroux* (part)

= Salicornia, *Schweigger*; Salicornaria, *Cuvier*; Salicornaria, *Busk*; Farcimia, *Fleming*.

Celaria fistulosa, *Linn.*. *Hincks*, 'Brit. Mar. Pol.' p. 106, pl. xiii. figs. 1–4. Hincks gives 14 recent and 10 fossil synonyms.
„ sinuosa, *Hassall, Hincks*, p. 109, pl. xiii. figs. 5–8.
„ Johnsoni, *Busk*, *Hincks*, p. 112, pl. xiii. figs. 9–12.
The last species: Shetland; Madeira; Algiers.

In the 'Challenger Report' the family contains the following genera:—

1. Salicornaria, *Cuvier*.
2. Melicerita, *Milne-Edwards*.

Genus 47. Salicornaria, *Cuvier*.

'Zoarium radicate, simple or branched, articulated or continuous; cylindrical, with the cells disposed round an imaginary axis; with or without avicularia. When articulated the internodes are connected by short straight tubes, or with the intervention of a convoluted knot of slender tubules.'—*Chal. Rep.* p. 86.

In the above Report Mr. Busk has devoted nearly five pages to the discussion of moot points of structure in the species of the genus irrespective of very full details of the new forms in the 'Challenger' material. The group is divided into three sections, which will be alluded to presently, and then he remarks that, 'speaking generally, the species of *Salicornaria* . . . may be grouped into those in which the areolation is fundamentally rhomboidal, and those in which it is strictly hexagonal' (*op. cit.* p. 87). After giving the 'Challenger' species I will give the list as furnished by Mr. Busk, in which the two sorts of areolation may be studied. It may be well to note that the closer study of the chitinous parts—given by Mr. Busk in the woodcuts—will afford ample and interesting details when dealing with the new or even the well-known species of this remarkable group. I do not, however, think that the new light thrown upon the 'Challenger' species will be lost or neglected in future researches of students of our British and foreign marine polyzoa.

§ Simplices, *Busk*.

Species in which the zoarium is single or composed of a single segment, &c.

1. Salicornaria clavata, *Busk*, 'Chal. Rep.' pl. xii. fig. 8, and woodcut, p. 88
= Cellaria fistulosa, *Macgillivray*, 'Nat. Hist. Vict.' Decade V. (not *Linn.*)
= C. fistulosa, *var.* australis, *Hincks*, 'Ann. Mag. Nat. Hist.' 5th ser. vol. xiii. p. 368, 1884.

§ β. Articulatæ (α, *tubulatæ*).

Species in which the internodes are connected by elastic or flexible joints, &c.

2. Salicornaria simplex, *Busk*, 'Chal. Rep.' pl. xxxiii. fig. 8, and woodcut, p. 88.

(*β, nodatæ*).

3. Salicornaria variabilis, *Busk*, 'Chal. Rep.' pl. xii. figs. 3, 9, and woodcut, p. 89.
4. „ divaricata, *Busk*, 'Chal. Rep.' p. 90, woodcut only.
5. „ bicornis, *Busk*, 'Chal. Rep.' pl. xxxiii. fig 9, and woodcut, p. 90
   = S. tenuirostris, *var. a*, bicornis, 'Brit. Mus. Cat.' pl. lxiii. fig. 4
   = (?) Cellaria tenuirostris, *Macgillivray*.
6. „ dubia, *Busk*, 'Chal. Rep.' pl. xii. fig. 2, and woodcut, p. 91.
7. „ Malvinensis, *Busk*, 'Chal. Rep.' pl. xii. figs. 1, 5, 7, and woodcuts, p. 91
   = S. Malvinensis, *Busk*, 'Brit. Mus. Cat.'
   = Cellaria *id.*, *Waters*, Bry. S.-W. Vict. 'Quart. Jour. Geol. Soc.' August 1881.
8. „ tenuirostris, *Busk*, 'Chal. Rep.' p. 92, woodcut
   = Salicornaria *id.*, 'Brit. Mus. Cat.'
   = Cellaria *id.*, *Smitt*, 'Florid. Bry.'
9. „ gracilis, *Busk*, 'Chal. Rep.' p. 93, woodcuts, p. 93
   = S. gracilis, *Busk*, 'Brit. Mus. Cat.'
   = S. punctata, *Busk*, 'Voy. of Rattles.'
   = Cellaria gracilis, *Macgillivray*.
   ? „ attenuata, *D'Orb*.
   ? „ tenella, *Lamk*.
   ? „ salicornarides, *Savig.*, 'Egypt.' pl. vi. fig. 7.

§ γ. Inarticulatæ.

10. Salicornaria magnifica, *Busk*, 'Chal. Rep.' pl. xii. figs. 4–6, woodcut, p. 94.

This is the whole of the *Salicornaria* amongst the 'Challenger' material, but on p. 87 of 'Report' Mr. Busk gives the list previously referred to.

§ α. *Areolation rhomboidal, articulation tubular.*

1. Salicornaria farciminodes, *Cuvier*.
2. „ sinuosa, *Haswell*.
3. „ simplex, *Busk* (No. 2 of 'Chal.' list).
4. (?) „ crassa (n. sp.), *Busk*.
5. „ hirsuta, *Kirchenpauer*.

§ β. *Areolation hexagonal, articulation nodular.*

6. Salicornaria variabilis, *Busk* (No. 3 of 'Chal.' list).
7. „ aciculata (n. sp.), *Busk*.
8. „ bicornis, *Busk* (No. 5 of 'Chal.' list).
9. „ dubia, *Busk* (No. 6 of 'Chal.' list).
10. „ Malvinensis, *Busk* (No. 7 of 'Chal.' list).
11. „ tenuirostris, *Busk* (No. 8 of 'Chal.' list).
12. „ Johnsoni, *Busk*.
13. „ „ *var.* gracilis, *Busk*.
14. (?) „ hexagonalis (n. sp.), *Busk*.

§ γ. *Inarticulatæ.*

15. Salicornaria magnifica, *Busk* (No. 10 of 'Chal.' list).

Genus 47. (?) Farcimia, *Pourtalès.*

Smitt, 'Florid. Bryozoa.'
Hincks, 'Ann. Mag. Nat. Hist.' vol. x. 5th ser. 1883.

Zoœcia calcareous, erect, branching; stem and branches composed of segments united by corneous joints. Zoœcia arranged in series round an imaginary axis, with elevated margins and a depressed area, which is more or less covered in with membrane.

'The genus instituted by Pourtalès,' says Mr. Hincks (*op. cit.* p. 199), 'and adopted by Smitt ('Florid. Bryozoa,' Part II. p. 2), includes forms with a Cellarian habit and a Membraniporidan cell.'

1. Farcimia cereus, *Pourtalès.*
2. „ appendiculata, *Hincks* (*op. cit.* 'Annals'), p. 199, pl. vii. fig. 4.
   Locality: Port Phillip Head (*J. B. Wilson*).

The striking feature of the new species are the avicularia. They are remarkable for their size, and in structure they seem to resemble the lateral appendage of *Scrupocellaria.*

Genus 48. Melicerita, *Milne-Edwards.*

Cellaria (sp.), *Waters* (see *Busk* for other synonyms).

'Zoarium compressed, bilaminar, rigid, lobate, ligulate, or foliaceous; articulated or continuous. Zoœcia usually disposed in transverse rows. Surface areolated. Area rhomboid or hexagonal. Orifice sub-central, semicircular, or oblong; border entire, with two articular teeth below and sometimes also above. Operculum corresponding in form to the orifice, supported by a chitinous ring, incomplete above.'—*Chal. Rep.* p. 95.

Mr. Busk says up to the present time the only known species referable to *Melicerita* were two, or perhaps three, fossil forms, viz.:—

1. Melicerita Charlesworthii, *Milne-Edw.*
2. „ angustiloba, *Busk.*
3. (?) „ achates, *D'Orb.* (Lateresehara).

In the 'Challenger Report' two other species are described as new:—

4. Melicerita atlantica, *Busk*, 'Chal. Rep.' pl. xiv. fig. 1, woodcuts, p. 96.
5. „ dubia, *Busk*, 'Chal. Rep.' pl. xxxii. fig. 10.

Family XVI. **Tubucellaridæ**, *Busk*

= Cellaridæ (pars), *D'Orb.*; Salicornariidæ (pars), *Macgil.*
= Porinidæ (pars), *Hincks.*

'Zoarium erect; radicate, composed of cylindrical internodes. Zoœcia disposed round an imaginary axis, convex, distinct, pyriform; peristome

produced, tubular. Surface reticulato-punctate, or simply punctate with or without a simple median pore on the front (often wanting). Avicularia and oœcia.'—*Chal. Rep.*

1. Genus Tubucellaria, *D'Orb.*
2. „ Siphonicytara, *Busk.*

In the family *Porinidæ*, as described by Mr. Hincks, 'Brit. Marine Polyzoa,' four genera were included, viz.:—

1. Genus Porina, *D'Orb.*
2. „ Anarthropora (part), *Smitt.*
3. „ Lagenipora, *Hincks.*
4 „ Celleporella, *Gray.*

In the classification of Mr. Busk only two of these four types are accounted for, and in justice to Mr. Hincks I have allowed species of these genera to precede the Tubucellariadæ, not as a part of Mr. Busk's grouping, but because they are not otherwise accounted for. Miss E. C. Jelly informs me that Lagenipora is far more widely distributed in British seas than was supposed when the original description was drawn up; and in some of his foreign Cheilostomata Mr. Hincks describes a new species of the same genus.

Family XII. Porinidæ, *D'Orb.*

(*Hincks*, 'Brit. Mar. Polyzoa,' p. 226.)

'Zoarium incrusting, or erect and ramified. Zoœcia with a raised tubular or sub-tubular orifice, and frequently a special pore in the front wall.'—*Op. cit.* p. 226.

Genus 51. (?) Lagenipora, *Hincks.*

'Colonies consisting of a number of cells immersed in a common calcareous crust. Zoœcia decumbent, contiguous, lageniform; oral extremity free, tubular, with a terminal orbicular orifice.'—*Op. cit.* p. 235.

1. Lagenipora socialis, *Hincks*, 'Brit. Mar. Pol.' vol. i. p. 235; vol. ii. pl. xxxiv. figs. 7, 8.
„ spinulosa, *Hincks*, 'Polyzoa of Queen Charlotte Island,' 'Annals,' January and March 1884.

Genus 52. (?) Celleporella, *Gray.*

'Zoœcia sub-erect, the anterior extremity tubular and free, with a terminal circular orifice. No special pores. Zoarium (in the British species) incrusting.'—*Brit. Mar. Pol.* p. 413.

1. Celleporella lepraloides, *Norman*, 'Quart. Jour. Mic. Soc.' (n. sp.) viii. p. 222, pl. vii. figs. 4, 5, 'Brit. Mar. Pol.' p. 414, woodcuts.
2. „ pygmea, *Norman*, Shet. Pol. 'Brit. Assoc. Rep.' 1868. 'Brit. Mar. Pol.' p. 415.

The other genera of Hincks's *Porinidæ* will be accounted for further on.

Genus 49. Tubucellaria, *D'Orb.* and *Macgil.*

Tubicellaria, *Heller, Risso, Costa*; Onchopora (sp.), *Busk.*

'Zoarium composed of cylindrical, usually quadriserial, internodes, articulated by flexible tubular peduncles, and arising either dichotomously from the extremity, or irregularly from the sides of the segment from which they spring. Zoœcia pyriform, prolonged, and attenuated downwards, ventricose above, and produced into a tubular peristome, bordered by a very thin septal ridge. A simple circular median pore (often absent) in front, immediately below the tubular peristome. Surface reticulate, scrobiculate, or simply and sparingly punctate.'—*Chal. Rep.*, p. 99.

The genus thus defined includes four known and well-marked forms, which, besides the sculpturing of the surface, possess the simple circular median pore. To these another species, provisionally named, is added by Mr. Busk, and this is sparsely punctured, and there is no trace of a median pore. The species are—

1. Tubucellaria opuntioides, *Pallas.*
2. „ cereoides, *Ell. & Sol.*
3. „ hirsuta, *Lamx.*
4. „ fusiformis, *D'Orb.*
5. „ cæca, *Busk* (provisional).

Of these only 1 and 3 occur in the 'Challenger' collection.

1. Tubucellaria opuntioides, *Pallas*, 'Chal. Rep.' pl. xxiv. fig. 7; pl. xxxvi. fig. 19 (pars).
2. Tubucellaria hirsuta, *Lamx.* 'Chal. Rep.' p. 100, pl. xxxvi. fig. 18.

Genus 50. Siphonicytara, *Busk.*

'Zoarium continuous, radicate, branched; branches alternate, subcylindrical quadriserial, subsecund. Zoœcia completely immersed below, flattened in front. Peristome tubular, extended. A circular median pore below the middle of the front. A large circular orifice (avicularian ?) near the top of most of the lateral zoœcia behind.'—*Chal. Rep.*, p. 101.

Siphonicytara serrulata, *Busk*, 'Chal. Rep.' pl. xv. fig. 2.

(For Genera 51 ? Lagenipora, *Hincks*; and 52 ? Celleporella, *Gray*, see *ante*, p. 553. For Genera 53 ? Rhyncopora, *Hincks*; 54 ? Schizotheca, *Hincks*; and 54*, Mastigophora, *Hincks*, see p. 101.)

Family XVII. **Onchoporidæ**, *Busk.*

'Zoarium flexible, continuous, branched or lobate, ligulate or foliaceous, then unilaminar. Zoœcia urceolate, ventricose. Orifice semicircular, with a straight entire lower lip. On the front, close below the orifice, a lunate fringed pore, and on each side an oblong or circular perforated disc, with a raised border.'—*Chal. Rep.*, p. 102.

Mr. Busk justifies himself in separating this small group from the genus Microporella of Hincks, although a number of other forms possess a similar lunate pore combined with a similarly shaped orifice. It appears to me that Mr. Busk is perfectly right in the course he has taken; but great credit, notwithstanding the separation, is due both to Mr. Hincks and to Mr. Waters on account of the calmly consistent manner in which species of the genus Microporella have been worked up.[1]

[1] Since the whole of this report was in the hands of the printer Mr. A. W. Waters's

Genus Onchopora, *Busk.*
„ Onchoporella, *Busk.*

Genus 55. Onchopora, *Busk*
= Carbasea (pars), *Busk*
= Malakosaria, *Goldstein.*

'Zoarium dichotomously branched, cylindrical, quadriserial.'—*Chal. Rep.*, p. 103.

Onchopora Sinclairii, *Busk*, 'Chal. Rep.' pl. x. fig. 4; 'Quart. Jour. Mic. Soc.' vol. v. p. 172
= Malakosaria pholaramphos, *Goldst.*, 'Proc. Roy. Soc. Vict.' June 1881, p. 5, pl. ii. fig. 1.

Genus 56. Onchoporella, *Busk*

= Carbasea (pars), *Busk*; Scruparia (pars), *Busk.*

'Zoarium foliaceous, unilaminar, ligulate, or lobed.'—*Chal. Rep.*, p. 103.

1. Onchoporella bombicina, *Busk*, 'Brit. Mus. Cat.'; 'Chal. Rep.' p. 104
= Flustra bombycinna, *Linn.*, *Bosc.*, *Lamx.*
= Semiflustra bombycina, *Lamk.*, *D'Orb.*
? Lepralia diadema, *Macgil.*
2. „ diaphana, *Busk*, 'Quart. Jour. Mic. Soc.' vol. viii. p. 281, pl. xxxi. fig. 1
= Scruparia, *id.*, *Busk*, 'Chal. Rep.' p. 104 (note).

Family XVIII. **Reteporidæ**, *Smitt*

= Reteporidæ, *Smitt*, 1867; *Hincks*, 1879.

Escharidæ (pars), *D'Orb*, 1851; *Hincks*, 1880; *Smitt*, 1872; 'Brit. Mus. Cat.' 1852, *Busk*, 'Crag Polyzoa,' 1859; *Macgillivray*, &c.

'Zoarium calcareous, erect, fixed; foliaceous and fenestrate, unilaminar, or reticulately or freely ramose in one plane. Zoœcia secund.' —*Chal. Rep.*, p. 104.

1. Genus Retepora, *Imperato*, 4 sections.
2. „ Reteporella, *Busk* (sub-genus, *Busk*).
3. „ Turritigera, *Busk.*

Genus 57. Retepora, *Imperato*

= Retepora (pars), *Lamx.*, *Blainv.* 'Brit. Mus. Cat.'
Eschara (pars), *Smitt*; Millepora (pars), *Linn.*, *Pallas.*, *Ellis.*

'Zoarium reticulate, formed of flexuose, anastomosing branches, or fenestrate; erect, springing with a calcareous stem, rarely from an incrusting or spreading base. Zoœcia disposed on one aspect only, usually deeply immersed, except on the sides of the branches or trabeculæ.

paper ('Cheilostomatous Bryozoa' from Aldinga, &c. *Quart. Jour. Geol. Soc.* Aug. 1885) has come to hand. I find that he takes exception to, and freely criticises Mr. Busk's arrangement in his prefatory remarks. I think it will be better to refer the student to the paper itself, rather than point out all the moot-points raised by Mr. Waters.

Primary orifice sub-orbicular or semicircular; border entire. Afterwards the peristome becomes much raised and multiform, usually fissured in the middle or one side in front, the fissure often becoming a sub-oral pore by the meeting of the upper angles. Very often a small avicularium on one of the angles, which is also frequently developed into a labial or pre-oral rostrum. Usually numerous adventitious avicularia on one or both aspects of the zoarium.'—*Chal. Rep.*, pp. 105, 106.

I suppose that there are not among the whole of the recent Polyzoa two more difficult groups to master the details of than the *Reteporæ* and the *Celleporæ*. I know too well that this is painfully true of the fossil species that have been placed in either of these respective groups. My early dissent from the supposed identity of the Palæozoic forms with recent species was very early expressed in my crude articles in 'Science Gossip,' and later on in the earlier of my 'British Association Reports' (Carboniferous, 1880, and Silurian, 1881); and it must be remembered that at this time very little attention had been paid to the inner structure of either fossil or recent forms, so that even up to a very recent date Palæozoic species, which were fenestrated by the inosculation of branches, were indifferently placed among the *Reteporidæ* as then understood. Within the last six or seven years a very great advance has been made in the study of parts of the zoarium of fossil species of Polyzoa; and the remark is especially applicable to the study of parts of the zoarium in recent forms of several groups of Polyzoa. One of the comparatively recent additions to our knowledge of parts of the zoaria of species is that of the Rossenplatten (communicative pores of Hincks), through which the endosarcal cords passed from cell to cell. This, though eminently available for the classification of recent species, is not so available for the more minute study of fossil species. Another more recent addition to our knowledge of the chitinous appendages of species was made by Mr. A. W. Waters in a communication to the Geological Section of the Manchester Literary and Philosophical Society, and ultimately published in their 'Proceedings' (vol. xviii. No. 2, Sess. 1878–9). The paper referred to was one on 'The Use of the Opercula in the Determination of the cheilostomatous Bryozoa.' Mr. Waters figures and describes thirty-seven species of operculæ, all magnified eighty-five times, and his specimens were selected from a much larger group of forms than those enumerated. This paper seems to have been entirely unknown to Mr. Busk until after the drawing up of the Descriptive Catalogue of the Species of *Cellepora* collected in the 'Challenger' Expedition ('Linn. Soc. Journ. Zoology,' vol. xv. 1881?). In a 'supplementary note respecting the use to be made of the chitinous organs in the Cheilostomata, &c.' ('Linn. Soc. Jour.' vol. xv.), Mr. Busk speaks his regret, acknowledges the value of the paper by Mr. Waters, and then says (*loc. cit.* p. 357): 'But having since devoted much attention to this point, and examined the characters not only of the operculum, as suggested by Mr. Waters, but also, in addition, those of the other chitinous elements of the skeleton in between sixty and seventy species of *Celleporæ*, as well as in numerous species of *Reteporæ* and *Salicornariadæ*, both groups in which the determination of species is often attended with considerable difficulty and uncertainty, I have become convinced that the characters derived from the chitinous organs will be found of the greatest possible utility, and at the same time capable of being employed with the utmost facility and precision.' The new knowledge derived from the study of the chitinous parts of recent

Polyzoa is one of the charms of the 'Challenger Report'; and Mr. Busk, in his admirable drawings and woodcuts, gives ample material for the beginning of a new speciality in the study of fossil and recent Polyzoa. Previous to the publication of the 'Challenger Report,' however, Mr. P. H. Macgillivray published a paper in the 'Proceed. Roy. Soc. Victoria,' Aug. 1883, on the chitinous parts of Polyzoa, and he remarks similarly of the value of the operculæ as previously mentioned by Mr. A. W. Waters.

Independent, however, of these labours on the chitinous appendages, Mr. Hincks devoted his attention to special groups of Polyzoa previous to the publication of the 'Brit. Marine Polyzoa'; and one of the most elaborate of these published papers is his Notes on the Genus *Retepora* ('Ann. Mag. Nat. Hist.' 5th ser. vol. i. 1878). In this paper is enumerated all the recent species described up to that time. This list is as follows:—

1. Retepora phœnicea, *Busk* = (?) R. indica, *D'Orb.*
2. ,, monilifera, *Macgil.*
3. ,, porcellana, *Macgil.*
4. ,, granulata, *Macgil.*
5. ,, fissa, *Macgil.*
6. ,, versipalma, *D'Blainv.* (? sp.)
7. ,, marsupiata, *Smitt* = R. cellulosa, *var.*
8. ,, reticulata, *Pourtalès* = (?) R. Beaniana, *var.*
9. ,, Wallichiana, *Busk & Hincks* = R. elongata, *Smitt.*
10. ,, Edwardsii = (?) R. cellulosa.
11. ,, Beaniana, *King.*
12. ,, cellulosa, *authors.*
13. ,, Couchii, *Hincks.*
14. ,, prætenuis, *Hincks.*
15. ,, plana, *Hincks.*
16. ,, tessellata, *Hincks.*
17. ,, robusta, *Hincks* = (?) R. porcellana, *Macgil.*

To which may be added, says Mr. Busk—

18. Retepora bi-avicularia, *Smitt* = R. Beaniana, *var.*
19. ,, altisulcata, *Ridley.*
20. ,, microthyris, *Busk* (MS.)
21. ,, umbonata, *Macgil.*, *var.* of R. monilifera.
22. ,, sinuata, *Macgil.* ,, ,,
23. ,, lunata, *Macgil.* (?) ,, ,,
24. ,, acutirostra, *Macgil.* (?) ,,
25. ,, munita, *Hincks* (?) ,, ,,
27. ,, formosa, *Macgil.*
28. ,, serrata, *Macgil.*
29. ,, aurantiaca, *Macgil.*
30. ,, laxa, *Hincks* (? *var.* porcellana, *Macgil.*)
31. ,, avicularis, *Macgil.*

To which must now be added the 'Challenger' species, bringing up the described or catalogued number to about fifty or sixty species.

§ *a. Reticulatæ.*

32. Retepora apiculata, *Busk*, 'Chal. Rep.' pl. xxv. fig. 6, woodcut, chitinous appendages, p. 108.

33. Retepora producta, *Busk*, 'Chal. Rep.' pl. xxv. fig. 7, woodcut, p. 108.
34. „ denticulata, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 1, woodcut, p. 109.

§ β. *Fenestratæ.*

Zoaria foliaceous, fenestrate.

35. Retepora Imperati, *Busk* (MS.), 'Chal. Rep.' pl. xxvi. fig. 9
= R. eschara marina, *Imperato*
= R. cellulosa, *a* (pars), *Auctt.*
= Millepora foraminosa, *Ell. & Sol.*
= R. elongata, *D'Orb. & Smitt, var.*

Mr. Busk gives a very elaborate account of these species, which occupies about two and a half pages of the Report, together with woodcut (fig. 19) of the chitinous parts of *R. imperati* and *R. elongata*, p. 111.

36. „ tessellata, *Hincks*, 'Chal. Rep.' pl. xxvii. fig. 8 (*Hincks*), 'Ann. Mag. Nat. Hist.' 1878.
37. „ *var. α*, cæspitosa, *Busk*, 'Chal. Rep.' pl. xxvii. fig. 6, woodcut, fig. 20, p. 113
=(?) R. tessellata, *Hincks.*
38. „ *var. β*, pubens, *Busk*, 'Chal. Rep.' pl. xxviii. fig. 3, woodcut, fig. 21.

§§. *Oœcium, with a vertical fissure in front.*

39. Retepora gigantea, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 7, woodcut, fig. 22, p. 114.
40. „ lata, *Busk*, 'Chal. Rep.' pl. xxvii. fig. 1, woodcut, fig. 23, p. 115.
41. „ crassa, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 10; pl. xxvii. fig. 3, woodcut, fig. 24, p. 115.
42. „ atlantica, *Busk* (?), 'Chal. Rep.' pl. xxviii. fig. 1, woodcut, fig. 25, p. 116.
= (?) R. cellulosa *var.* marsupiata, *Smitt.*

§§. *Oœcium with a trifoliate stigma in front.*[1]

43. Retepora victoriensis, *Busk*, 'Chal. Rep.' pl. xxvii. fig. 7, woodcut, fig. 26, p. 117
= (?) R. carinata, *Macgil.*
44. „ *Var.* japonica, 'Chal. Rep.' p. 118, woodcut, fig. 27.
45. „ simplex, *Busk*, 'Chal. Rep.' pl. xxviii. fig. 4, woodcut, fig. 28, p. 118.
46. „ hirsuta, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 4, woodcut, fig. 29, p. 119
= (?) R. monilifera, *Macgil.*, *Hincks.*
47. „ mucronata, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 6.
48. „ contortuplicata, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 2, woodcut, fig. 30, p. 120.
49. „ cavernosa, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 8, woodcut, p. 121, fig. 31.

[1] Respecting this peculiar stigma in front Mr. Busk (p. 117) adds in a note a few particulars about the original remarks of Macgillivray, made more than twenty years ago, but which seem to have attracted but little attention by authors.

50. Retepora tubulata, *Busk*, 'Chal. Rep. pl. xxviii. fig. 2, woodcut, p. 122, fig. 32.
51. " columnifera, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 5, woodcut, p. 122, fig. 33.
52. " Philippinensis, *Busk*, 'Chal. Rep.' pl. xxvii. fig. 5.
53. " Phœnicea, *Busk*, 'Chal. Rep.' p. 124, woodcut, and 'Brit. Mus. Cat.'

§§ 4. *Oœcia inconspicuous or unknown.*

54. Retepora delicatula, *Busk*, 'Chal. Rep.' pl. xxvi. fig. 3, woodcut, fig. 35, p. 124.
55. " margaritacea, *Busk*, 'Chal. Rep.' pl. xxvii. fig. 2, woodcut, p. 125.
56. " Jacksoniensis, *Busk*, 'Chal. Rep.' pl. xxvii. fig. 4, woodcut, p. 125.
57. " Magellensis, *Busk*, 'Chal. Rep.' pl. xxxvi. fig. 20.

Under the fenestrate section of the *Reteporidæ* Mr. Busk ('Challenger Report,' p. 104, note) says that Macgillivray's species, PETRALIA UNDATA, may be included in a sub-genus. I have a specimen of Macgillivray's species from Port Phillip Heads, but I have not Macgillivray's description. It is a very peculiar fenestrated form, with cells on one side only, and if it be included among the RETEPORIDÆ, it must be on account of its 'foliaceous and unilaminar character.' The cells and also the ovicells have a very distinctive feature.

Sub-genus 58. Reteporella, *Busk.*

'Characters those of *Retepora*, but the branches free in one plane.' *Chal. Rep.* p. 126.

This appears to me to be rather an important separation, because there are many fossil species of *Retepora* which are neither fenestrate nor reticulate, but which have all the characters of ordinary species. These may now be placed in this sub-genus, to the great advantage of the student of fossil forms.

1. Reteporella flabellata, *Busk*, 'Chal. Rep.' pl. xxv. fig. 5, woodcut, p. 126, fig. 38.
2. " myriozoides, *Busk*, 'Chal. Rep.' pl. xxiv. fig. 2.

Genus 59. Turritigera, *Busk.*

'Zoarium ramose, arising from a calcareous expansion, incrusting foreign bodies, having the openings of the zoœcia usually on one side only. Zoœcia ventricose or flask-shaped, much produced and sub-tubular above, with several conical or columnar avicularian processes on the peristome.'—*Chal. Rep.* p. 129.

Turritigera stellata, *Busk*, 'Chal. Rep.' pl. xxiv. fig. 1.

Mr. Busk very truly remarks that this 'form appears to be more nearly allied to Retepora than to any other generic group, but the very curious conformation of the oral portion and aperture, and its other peculiarities, seem to justify its being considered as generically distinct.'

One can hardly help speaking of the very admirable way in which Mr. Busk has dealt with this remarkable group. His descriptions and

diagnoses occupy about twenty-six pages, two and a half of which number are devoted to the geographical and bathymetrical range of species. This part of the Report, however, will appear in its proper place further on.

In justice to Mr. Hincks and to Mr. A. W. Waters, after the very full remarks on the species by Mr. Busk, it would appear to me very unwise to pass over the labours of these respected authors.

Notes on the genus Retepora, with descriptions of new species. By the Rev. Thomas Hincks, 'Ann. Mag. Nat. Hist.' May 1878.

Mr. Hincks begins this paper by giving a list of previously described species from different seas by different authors. From Australia five species; from the South seas, one; from India, one; from Florida, three; from the Arctic and North seas, two; and from the British and Mediterranean seas, two: after which he proceeds with a very full description of new or little known species.

Genus Retepora, *Lamarck.*

α. *With an oral fissure.*

1. Retepora Couchii, *Hincks* (*op. cit.* p. 355, pl. xviii. figs. 1–6)
   = Retepora Beaniana, *Hincks*, 'Dev. and Cornwall Cat.'
   = „ cellulosa, *var.* Beaniana, *Manzoni.*
2. „ prætenuis, *Hincks* (*op. cit.* p. 356, pl. xix. figs. 6, 8).

β. *Without an oral fissure.*

3. „ plana, *Hincks* (*op. cit.* p. 358, pl. xviii. figs. 7, 8).
4. „ tessellata, *Hincks* (*op. cit.* p. 358, pl. xix. figs. 9–12).
5. „ robusta, *Hincks* (*op. cit.* p. 359, pl. xviii. figs. 9–10).

Mr. Hincks says that the following species have already been described,[1] but he ventures to give a fuller diagnosis:—

6. Retepora monilifera, Macgil. (*Hincks, op. cit.* p. 360, pl. xix. figs. 1–5).
7. „ Phœnicea, *Busk*, 'Cat. Mar. Pol.'
8. „ granulata, Macgil. (*Hincks, op. cit.* p. 363, pl. xix. figs. 13–15).
9. „ cellulosa, Smitt (*Hincks, op. cit.* p. 364).

Family XIX. **Cribrilinidæ,** *Hincks.*

'Brit. Mar. Pol.' vol. i. p. 182; 'Chal. Rep.' p. 130.

Mr. Hincks's description of this family group is as follows:—

'Zoarium adnate, forming an indefinite crust, or erect. Zoœcia having the front wall more or less fissured, or traversed by radiating furrows.' Mr. Busk, however, adds to his description other characters, and slightly modifies the remarks of Mr. Hincks:—

'Zoarium crustaceous, or adnate (lepralian), or erect and unilaminar (hemischaran). Zoœcia, front with transverse or radiating fissures or rows of punctures without fissures. Mouth simple, sub-orbicular, sometimes mucronate or semicircular; with or without a median sub-oral pore.'—*Chal. Rep.* p. 130.

[1] *Notes on the Cheilostomatous Polyzoa of Victoria and other parts of Australia* (P. H. Macgillivray), 'Trans. Phil. Inst. Victoria,' vol. iv. 1860, p. 168, &c.

Genus 60. Cribrilina, *Gray*.

Cribrilina, *Gray*, *Hincks*, *Smitt*, *Busk*, 'Chal. Rep.'
Lepralia (pars), *Busk*, 'Brit. Mus. Cat.' *Johnst.*
Repteschareila, *D'Orbigny*, 'Pal. Franc. Tert. Cret.'
Escharipora, *Smitt*, 1867.

'Front of cells fissured, or simply punctured in regular or transverse rows.'—*Busk*, 'Chal. Rep.'

In the 'British Marine Polyzoa' Mr. Hincks describes the following species. Except in some few instances I have not thought it wise to reproduce the whole of the synonyms given by authors, as a very full list was appended to a previous list in the Fifth Report on Fossil Polyzoa, 'Brit. Assoc. Rep.' and is furnished (from Busk and Hincks) in the introductory part of the present Report.

1. Cribrilina radiata *Moll.* (*op. cit.* pl. xxv. 1–9).
   Var. α, Antrim, deep water.
   Var. β, (*op. cit.* pl. xxv. fig. 4).
   Var. γ, tenuirostris, Madeira.
2. ,, punctata, *Hassall* (*op. cit.* pl. xxvi. figs. 1–4; pl. xxiv. fig. 3).
   Var. α, with a central umbo.
3. ,, annulata, *Fabric.* (*op. cit.* pl. xxv. figs. 11, 12).
4. ,, figularis, *Johnst.* (*op. cit.* pl. xxvi. figs. 5–7).
   Var. α, fissa.
5. ,, Gattyæ, *Busk* (*op. cit.* pl. xxv. fig. 10).
   Var. α, Hastings, *Miss E. C. Jelly.*

Many of these species have a wide geographical range both around our coast, some of them reaching far north. The varieties are very local.

Only one genus—*Cribrilina*—is at present admitted by Mr. Busk in his classified list, but in the classification of Mr. Hincks another genus, Membraniporella, *Smitt*, forms part of Cribrilinidæ, *Hincks*. In the definition, however, of Mr. Busk, the *hemischaran* forms of Mr. Hincks are included.

In the 'Challenger Report' the following species are described in several sections by Mr. Busk.

§ α. *Front fissured.* §§ 1. *Adnate* (*lepralian*).

1. Cribrilina radiata, *Moll.*, 'Chal. Rep.' p. 131. Found only in two stations, 75 and 135 A.
2. ,, latimarginata, *Busk*, 'Chal. Rep.' pl. xxii. fig. 10. One station only 320 on dead coral. In his remarks Mr. Busk says that Reuss describes and figures in his 'Palæon. Stud.,' under the name of *Celleporaria radiata*, a form in so many respects closely resembling his *C. latimarginata*. In other respects there is a difference.

§§ 2. *Free, erect or decumbent* (*hemischaran*).

3. Cribrilina philomela, *Busk*, 'Chal. Rep.' pl. xvii. fig. 6
   = (?) C. speciosa, *Hincks*, 'Ann. Mag. Nat. Hist.' 1881
   = (?) Repteschareila inæqualis, *D'Orb.*
   Var. α, adnata, *Busk*, 'Chal. Rep.' pl. xxii. fig. 7.
   (?) C. figularis, *var. Hincks.*

§ *β*. *Front with punctures in more or less distinct transverse rows.*

4. Cribrilina labrosa, *Busk.*
   Var. α, fragilis, *Busk*, 'Chal. Rep.' pl. xix. fig. 4.
5. „ monoceros, *Busk*, 'Chal. Rep.' pl. xix. fig. 8
   = (?) Lepralia larvalis, *Busk*, 'Brit. Mus. Cat.'

It might be a question, says Mr. Busk, whether the numerous forms that would come under § *β* should not be considered generically distinct from the fissured ones, p. 134.

Leaving this question to be settled by special workers on recent forms of Polyzoa, I will now give as full a list as possible of additions to the Cribrilinidæ by Mr. Hincks since the publication of the 'British Marine Polyzoa.' In his Contributions, 'Annals,' July 1880. After describing the Madeira species, C. radiata, *Moll.*, in J. Y. Johnson's material, Mr. Hincks said that, besides the British species, he only knew three others that could be referred to the genus Cribrilina.

Cribrilina cribrosa, *Heller*
= Lepralia cribrosa, *Heller.*
„ Jaubertii, *Audouin*
= Flustra Jaubertii, *Aud.*
„ Floridana, *Smitt.*

In his paper on the Polyzoa from Bass's Straits (Captain Warren's collection, now in the Liverpool Free Museum) four species are described, two of which are new. ('Annals' and 'Mag. Nat. Hist.' July 1881).

Cribrilina ferox, *Macgillivray.*
„ tubifera, *Hincks* (*op. cit.* pl. i. fig. 7).
„ speciosa, *Hincks* (*op. cit.* pl. i. fig. 8).
„ (?) monoceros, *Macgil.* (*op. cit.* pl. iii. fig. 6).

Mr. Hincks has placed under Macgillivray's name the Bass's Straits form, but only doubtfully. It is not Busk's *C. monoceros*, but it is allied to *C. punctata.*

In the papers on the Polyzoa of Queen Charlotte Islands, two other species are described and illustrated:—

Cribrilina furcata, *Hincks*, 'Ann. Mag. Nat. Hist.' Dec. 1882, pl. xx. fig. 5.
„ hippocrepis, *Hincks* (*op. cit.* pl. xx. fig. 6, 6*a*).
Loc.: Cumshewa; Houston Stewart Channel, abundant.
„ radiata, form innominata.
Form with vibraculoid setæ not uncommon (*op. cit.*) Jan. 1883.

Mr. Hincks says that some beautiful varieties of this variable species occur in the material from Queen Charlotte Islands, 'and the form which bears vibraculoid setæ is especially remarkable for richness of sculpture and delicacy of structure.'

See also the preliminary paper on the New Species in the Queen Charlotte Islands Collection, 'Ann. Mag. Nat. Hist.' Sept. 1882, pp. 248–256. No plates.

Genus 61. Membraniporella (*pars*), *Smitt.*

See Hincks, 'Brit. Mar. Polyzoa,' p. 199.
'Florid. Bryozoa,' *Smitt*, Part II, p. 10.

'Zoarium incrusting, or rising into free, foliaceous expansions, with a single layer of cells (hemischaran) (?) *Busk.* Zoœcia closed in front by a number of flattened calcareous ribs more or less consolidated.'—*Brit. Mar. Polyzoa*, p. 199.

1. Membraniporella nitida, *Johnst.*, *op. cit.* pl. xxvii. figs. 1–8.
2. " melolontha, *Busk*, *op. cit.* pl. xxvii. figs. 9, 10.

Family XX. **Microporellidæ.**

Microporellidæ (*pars*), *Hincks*, 'Brit. Mar. Pol,' p. 204.
This family as established by Mr. Hincks ('Brit. Mar. Pol.') embraced three genera:—

Genus Microporella, *Hincks.*
" Diporula, *Hincks.*
" Chorizopora, *Hincks.*

In the 'Challenger Report' (p. 134) Mr. Busk has modified the definition of Mr. Hincks for the purpose of 'limiting it to such Escharine forms as have a true lunate pore. Consequently, as here understood, it corresponds with Professor Smitt's genus *Porrelina* ("Florid. Bryoz." p. 27).' The genus *Chorizopora*, Hincks, is relegated to the next family, Escharidæ, and *Diporula*, Hincks, is not accounted for in the 'Challenger Report.'

'Mouth semicircular or coarctate, with an entire straight lower border; a lunate fimbriated median pore. Zoarium erect and bilaminar, or crustaceous and adnate.'—*Chal. Rep.* p. 134.

§ α. *Erect, bilaminar.*

Genus Flustramorpha, *Gray.*

§ β. *Crustaceous.*

Genus Microporella, *Hincks.*

§ α. *Erect, bilaminar.*

Genus 62. Flustramorpha, *Gray*

= Mastigophora (*pars*), *Hincks.* (See p. 101.)

'Zoarium erect, radicate, bilaminar, composed of irregular lobes, bordered and loosely interconnected by chitinous tubes; mouth coarctate; a lateral pouch-like vibracularium.'—*Chal. Rep.* p. 135.

1. Flustramorpha marginata, *Krauss* (sp.), 'Chal. Rep.' pl. xx. fig. 8, woodcut, p. 135
   = Flustra marginata, *Krauss*
   = Flustramorpha marginata, *Gray.*
2. " hastigera, *Busk*, 'Chal. Rep.' pl. xxi. fig. 7, woodcut, p. 136
   = (?) Porellina ciliata, *Smitt.*

In the Report, p. 136, Mr. Busk indicates other species as belonging to this group, but these are not in the 'Challenger' collection.

3. Flustramorpha flabellaris, *Busk*.
4. „ patagonica, *Busk* (MS. ?)

Genus 63. Microporella, *Hincks* (*Busk* ?).

'Zoarium erect and bilaminar, or incrusting and adnate. Mouth semicircular, with a straight entire lower border, with or without oral spines. An aviculario-vibracular organ on one side of the front, with the mandible forked at the base, or unarmed.'—*Chal. Rep.* p. 137.

1. Microporella personata, *Busk*, (sp.), 'Chal. Rep.' p. 137, woodcut
   = Lepralia personata, *Busk*
   = Microporella ciliata, *var.*, *Hincks*.
2. „ Malussi, *Aud.*, 'Chal. Rep.' p. 137.
3. „ ciliata, *Pallas*, (sp.), 'Chal. Rep.' p. 138.

These are the whole of the *Microporella* given by Mr. Busk in the 'Challenger Report.' As Mr. Hincks has, however, added to the list considerably since the publication of the 'British Marine Polyzoa,' I add the whole to the above without abridgment. As Mr. Busk's estimate of some of his own species, formerly described in the 'British Museum Catalogue,' differs from that of Mr. Hincks, it will be far better for the student of Marine Polyzoa to compare one author with the other before giving a decision either way. It is very certain that some at least of the species of Mr. Hincks will have to be turned over to other genera.

Genus Microporella, *Hincks*.

'British Marine Polyzoa,' vol. i. p. 204, which see for synonyms.

'Zoarium incrusting. Zoœcia with a semicircular aperture, the lower margin entire, and a semi-lunate or circular pore below it.'—*Op. cit.* p. 204.

'We do not know,' says Mr. Hincks, 'the physiological import of the definitely shaped opening in the front wall of the cell, which belongs to this genus. But the character, which is constant, may fairly be accounted of considerable importance, and, taken in combination with the form of the aperture, is a good diagnostic mark.'

1. Microporella ciliata, *Pallas*, *Hincks*, *op. cit.* p. 206, pl. xxviii. figs. 1–8.
   „ *Var. α*, personata, p. 207
   = Lepralia personata, *Busk*.
2. „ Malusii, *Aud.*, *op. cit.* p. 211, pl. xxviii. figs. 9–11; pl. xxix. fig. 12.
   Var. α, thyreophora, p. 212
   = Lepralia thyreophora, *Busk*.
3. „ impressa, *Aud.*, *Hincks*, *op. cit.* p. 214, pl. xxvi. figs. 9–11; pl. xxix. figs. 10, 11.
   Var. α, bimucronata, *Moll.*
   Var. cornuta, *Busk*.
   Var. β, glabra. *Aud.*
   „ *γ*, pyriformis, *Busk*.
4. „ violacea, *Johnst.*, *op. cit.* p. 216, pl. xxx. figs. 1–4.
   Var. β, plagiopora, *Busk*. Crag form.

These are the British species given by Mr. Hincks. The whole have a wide geographical range—and their range in time is also great—but principally Tertiary.

In his paper on the Madeira species, 'Ann. Mag. Nat. Hist.' July 1880, Mr. Hincks adds to the list—

5. Microporella decorata, *Reuss* (near ally of M. violacea), and suggests that the following species should be included in the list:—

Lepralia californica, *Busk.*
,, personata, *Busk.*
,, bicristata, *Busk.*
,, diadema, *Macgil.*
,, ceramia, *Macgil.*

6. Microporella ciliata, form vibraculifera, *Hincks*, Polyzoa Queen Charlotte Is. 'Annals,' Jan. 1883, pl. xvii. fig. 2.
7. ,, form, umbonata, *op. cit.* pl. xvii. fig. 1.
8. ,, ,, californica, *op. cit.* pl. xvii. fig. 3 =Lepralia *id.*, *Busk*, Quart. Jour. Mic. Soc. 1850. p. 310
9. ,, diadema, *Macgil.*, Polyzoa Bass's Straits.
10. ,, fuegensis, *Busk*, 'Annals,' May 1884 Tierra del Fuego.
11. ,, mucronata, *Macgil.*, Pol. Bass's Straits. Very abundant. This species belongs to the same section of the genus as our M. violacea = Eschara mucronata, *Macgil.*
12. ,, fissa, *Hincks*, 'Ann. Mag. Nat. Hist.' Nov. 1880, 5th ser. vol. vi. p. 381, pl. xvii. fig. 4. *Loc.*: Indian Ocean.

To the description of the above Mr. Hincks adds another brief list of *Microporella* :—

13. Microporella coronata, *Audouin* = Flustra *id.*, *Aud.*
14. ,, marsupiata, *Busk* = Lepralia *id.*, *Busk.*
15. ,, stellata, *Verrill* = Porellina *id.*, *Verrill.*

In his paper on the Polyzoa of New Zealand and Australia ('Annals,' March 1885), Mr. Hincks gives the following:—

Microporella Malusii, *Aud.*
16. ,, form disjuncta, *Hincks*, pl. vii. fig. 4. New Zealand.
9. ,, diadema, *Macgil.*
17. form angustipora, *Hincks*, pl. viii. fig. 3.

And to the above the following in all probability may be added:—

18. Microporella bicristata, *Busk* = Lepralia *id.*
19. ,, ceremia, *Macgillivray* = Lepralia *id.*
20. ,, serrulata, *Smitt* = Porina *id.*, *Smitt.*
21. ,, sub-sulcata, *Smitt* = Porina *id.*, *Smitt.*

Family **Monoporellidæ**, *Hincks.*

Genus Monoporella, *Hincks.*

'Zoœcia destitute of a membranous area or aperture, and of raised margins; orifice arched above, with the lower lip entire; no special pores.' *Hincks*, 'Annals.'

Originally Mr. Hincks founded the genus *Monoporella* for species of the *Microporellidian* orifice, but destitute of the median pore, which is so striking a character of the genus *Microporella*. Subsequently the author arranged the few known recent forms under the family name given above. Mr. Waters adopted the name—provisionally—for the fossil species which are given in the fifth Report on Fossil Polyzoa (*mihi*). As yet we have hardly material enough for a full study of the type. The genus is not given by Mr. Busk in his 'Challenger Report.'

1. Monoporella nodulifera, *Hincks*, Polyzoa from Bass's Straits, 'Liverpool Address,' April 1881.
2. „ lepida, *Hincks* (*op. cit.* April 1881).
3. „ albicans, *Hincks*, 'Ann. Mag. Nat. Hist.' Feb. 1882, pl. v. figs. 5–5*b*. *Loc.*: Singapore or Philippines.
4. „ brunnea, *Hincks*, 'Ann. Mag. Nat. Hist.' June 1883, pl. xviii. fig. 4. *Loc.*: Queen Charlotte Islands.

Family **Cyclicoporidæ**, *Hincks*.

'Ann. Mag. Nat. Hist.' October 1884.

Zoœcia having the front wall wholly calcified and destitute of raised margins or depressed area, with a more or less orbicular orifice.

Genus Cyclicopora, *Hincks*.

'Zoœcia with a perfectly simple orifice, more or less orbicular. Zoarium incrusting.'—*Ibid.* p. 279.

Cyclicopora longipora, *Macgil.* (sp.) = Lepralia *id.*
= C. prælonga, *Hincks*, 'Annals,' October 1884, p. 279, pl. ix. fig. 7. *Loc.*: Port Phillip Heads, *J. B. Wilson.*

In the *Escharidæ* Mr. Busk includes no fewer than fourteen genera, and as the family partly supersedes the *Myriozoidæ* of Smitt and Hincks, the following genera are left out in the classification of Mr. Busk in the 'Challenger Report.' They will be reported upon when I have concluded the family arrangement as given in the 'Challenger' monograph.

Genus Umbonula, *Hincks*.
„ Palmicellaria, *Alder*.
„ Rhynchopora, *Hincks*.
„ Schizotheca, *Hincks*.
„ Phylactella (part), *Hincks*.

Family XXI. **Escharidæ**.

'Challenger Report,' *Busk*, p. 138.

Escharidæ (*pars*), *Johnston*, *D'Orb.*, *Busk*, *Smitt*, *Hincks*, &c.
Myriozoidæ (*pars*), *Smitt*, *Hincks*.

'Zoarium calcareous, radicate or fixed; erect, uni- or bi-laminar, foliaceous or ramose, or crustaceous, loosely attached or adnate. Zoœcia urceolate, front entirely calcified.'—*Busk*, 'Chal. Rep.' p. 138.

1. Genus Eschara, *Pallas.*
2. ,, Lepralia, *Johnston.*
3. ,, Chorizopora, *Hincks.*
4. ,, Porella, *Gray.*
5. ,, Escharoides, *Smitt.*
6. ,, Smittia, *Hincks.*
7. ,, Mucronella, *Hincks.*
8. ,, Aspidostoma, *Hincks.*
9. ,, Schizoporella, *Hincks.*
10. ,, Gephyrophora, *Busk.*
11. ,, Myriozoum, *Donati.*
12. ,, Haswellia, *Busk.*
13. ,, Tessaradoma, *Norman.*
14. ,, Gemellipora, *Smitt.*

§ 1. *Lower lip of primary orifice entire.*

§§ *a. Erect, bilaminar.*

Genus 64. Eschara, *Pallas.*

Cellaria (*pars*), *Reuss*; Acropora (*pars*), *Reuss*; Lepralia (*pars*), *Hincks, Smitt.*

'Zoarium erect (sometimes decurrent); foliaceous or ramose, compressed, bilaminar.'—*Chal. Rep.* p. 141.

1. Eschara elegantula, *D'Orb.*, 'Chal. Rep.' pl. xx. fig. 6
= E. saccata, *Busk*, 'Ann. Mag. Nat. Hist.' 1856.
2. ,, gracilis, *Lamk.*, 'Chal. Rep.' pl. xxi. fig. 6
= Cellaria and Acropora coronata, *Reuss*
= Eschara Buskii, *Tenison Woods.*
No *Eschara* are described by Mr. Hincks in his 'British Marine Polyzoa'; and, so far as I am aware, only one species has been added to the list in his various publications since the issue of that work.
3. ,, glabra, *Hincks*, Polyzoa from Barrent's Sea, 'Annals,' Oct. 1880, p. 281, pl. xv. fig. 6.
4. ,, perpusilla, *Busk*, 'Linn. Soc. Jour. Zool.' vol. xv. 1880, pl. xiii. fig. 5. *Loc.*: Arctic Sea.
Associated with this species in the collection of Mr. Busk as described in the above paper is Eschara elegantula, *D'Orb.*

§§ *β. Crustaceous, unilaminar.*

Genus 65. Lepralia, *Johnston.*

Lepralia, *Hincks, Smitt* (*pars*), *Busk*, 'Brit. Mus. Cat.'; Hemischara (*pars*), *Busk.*

Zoarium unilaminar, erect or crustaceous, and loosely or wholly unattached, or adnate with the zoœcia, incomplete behind.

(a). *Unilaminar, erect or crustaceous, free or loosely attached* (*hemischaran*), 'Chal. Rep.' p. 142.

1. Lepralia celleporoides, *Busk*, 'Chal. Rep.' pl. xvii. fig. 4.
2. ,, japonica, *Busk*, 'Chal. Rep.' pl. xvii. fig. 5.

3. Lepralia tuberosa, *Busk*, 'Chal. Rep.' pl. xvii. fig. 7.
4. „ dorsiporosa, *Busk*, 'Chal. Rep.' pl. xviii. fig. 4.

(b). *Adnate (lepralian)*.

5. „ fuegensis, *Busk*, 'Chal. Rep.' pl. xxii. fig. 9.
6. „ margaritifera, *Quoy & Gaymard*
   = Flustra *id.*, *Quoy & Gaymard*
   = Lepralia *id.*, *Busk*, 'Brit. Mus. Cat.' and 'Chal. Rep.' p. 145.
7. „ incisa, *Busk*, 'Chal. Rep.' p. 145, woodcut, fig. 42.
8. „ lonchæa, *Busk*, 'Chal. Rep.' p. 146, woodcut, fig. 43.
9. „ marsupium, *Macgillivray*, 'Chal. Rep.' p. 147, woodcut
   = Porella *id.*, *Hincks*
   = (?) Porella minuta, *Norman*
   = Schizoporella marsupium, *S. O. Ridley*.

The above are the whole of the species of *Lepralia* given by Mr. Busk in the 'Report.' Mr. Hincks, however, in his 'British Marine Polyzoa,' and also in the 'Contributions to a General History of the Marine Polyzoa,' adds to the list of species considerably, and the following is a full compilation from the various sources up to date :—

§. *With a simple primary orifice only.*

10. Lepralia Pallasiana, *Moll.*, 'Brit. Mar. Pol.' p. 297, pl. xxxiii. figs. 1–3; pl. xxiv. fig. 4.
11. „ canthariformis, *Busk*, *op. cit.* pl. xxxiii. fig. 4; *Busk*, 'Quart. Jour. Mic. Soc.' 1860.
   Loc.: Shetland, deep water.
12. „ foliacea, *Ell. & Sol.*, *Hincks*, p. 300, pl. xlvii. figs. 1–4.
   Var. α, fascialis, *Hincks*.
   Var. β, bidentata, *Milne-Edw.*, pl. xlvii. fig. 4.
   'For the occurrence on our coast of the remarkable variety *fascialis*, which is common in the Mediterranean, we have only the authority of Pallas, who says that he had seen a specimen from the Isle of Wight.'
   Two varieties of *L. foliacea*, Joliet has observed at Roscoff—one red and the other white. The Minch, Hebrides, is the most northern locality recorded.
   Var. α, South Devon.
13. „ pertusa, *Esper.*, *Hincks*, p. 305, pl. xliii. figs. 4, 5.
14. „ adpressa, *Busk*, *op. cit.* p. 307, pl. xxxiii. figs. 5–7.
15. „ Hippopus, *Smitt*, *op. cit.* pl. xxxiii. figs. 8, 9). *Loc.*: Northumberland coast. The only British locality.
16. „ edax, *Busk*, *op. cit.* p. 311, pl. xxiv. figs. 7, 7*a*.
17. „ polita, *Norman*, *op. cit.* p. 315, pl. xxxii. fig. 5. *Loc.*: Shetland; The Minch.

(The whole of the British *Lepralia* given by Mr. Hincks.)

18. „ Kirchenpaueri, *Heller*.
   Var. α, teres, *Hincks*, 'Annals,' July 1880, pl. ix. figs. 7, 7*a*. *Loc.*: Madeira.
19. „ cleidostoma, *Smitt*, Australian *var.* *Var.* orbicularis, *Hincks*, 'Annals,' Aug. 1881, p. 122.
20. „ Poissonii, *Aud.* (? = Escharella setigera, *Smitt*). *Loc.*: Common. Bass's Straits; Florida. 'Ann. Mag. Nat. Hist.' August 1881, p. 122.

21. Lepralia nitescens, *Hincks*, 'Ann. Mag. Nat. Hist.' June 1883, pl. xviii. fig. 6.
22. „ bilabiata, *Hincks*, *op. cit.* Jan. 1884, pl. iii. fig. 1.
23. „ claviculata, *Hincks*, *ibid.*, pl. iii. fig. 3.
„ cleidostome (19) *Smitt*, *ibid.* March 1884. *Loc.*: The species and variety. Queen Charlotte Islands.
24. „ robusta, *Hincks*, 'Annals,' May 1884, pl. xiii. fig. 4. *Loc.*: India; coast of Burmah.
25. „ foraminigera, *Hincks*, 'Annals,' March 1883, p. 200, pl. vii. fig. 1.
26. „ rectilineata, *Hincks*, *ibid.* p. 201, pl. vii. fig. 5. *Loc.*: New Zealand (*Miss E. C. Jelly*).
27. „ bifrons, *Hincks*, 'Annals,' May 1884, p. 281, pl. viii. fig. 3. *Loc.*: Port Phillip Heads, Victoria.
28. „ cincta, *Hincks*, 'Annals,' May 1885, pl. viii. fig. 6.
29. „ subimmersa, *Macgil.*, *ibid.* pl. viii. fig. 1. *Loc.*: New Zealand (28); Port Phillip Heads, Victoria (29).
30. „ striatula, *Hincks*, 'Annals,' August 1882, pl. viii. fig. 2. *Loc.*: Zanzibar.

The following are also referable to the genus :—

31. Lepralia inornata, *Smitt*.
32. „ turrita, *Smitt*.
33. „ rostrigera, *Smitt* = Escharella *id.*, 'Florid. Bryozoa.'
34. „ Audouinii, *Smitt* = „ „ „
35. „ setigera, *Smitt* = „ „ „
36. „ depressa, *Busk*.
37. „ gigas, *Hincks*, 'Annals,' March 1885, pl. ix. fig. 8. *Loc.*: Trincomalee.
38. „ vestita, *Hincks*, *ibid.* pl. ix. fig. 9. *Loc.*: Tahiti, Fiji Islands.
39. „ radiatula, *Hincks*.
40. „ punctata, *Hincks*.

In a rather full list of Macgillivray, Australian species[1] kindly compiled for me by Miss E. C. Jelly, other *Lepralia* are catalogued. These I give, as well as other forms, on Macgillivray's authority. Some of his species have been adopted by Mr. Hincks and Mr. Busk: these do not appear in the list, but as they are fully referred to in the body of the present Report, the absent names will not cause any surprise.

Genus 66. Chorizopora, *Hincks*

= Mollia (sp.), *Smitt*; Hippothoa (*pars*), *Smitt*.
Schizoporella (*pars*), *Hincks*.

'Zoœcia often distinct, connected by hollow calcareous processes. Mouth semicircular or sub-orbicular, with a straight or sinuated lower border. Oœcial orifice crescentic. Wall of zoœcia usually transversely wrinkled.'—*Chal. Rep.* p. 148.

1. Chorizopora Brongniartii, *Aud.* (sp.), 'Chal. Rep.' p. 148, for synonyms.

[1] This list will be found among the Australian and Pacific lists on pp. 163–166.

2. Chorizopora hyalina.
Var. Bougainvillei, *Busk*
=Escharina Bougainville, *D'Orb.*
=Lepralia hyalina, *var.* Bougainvilla, *Busk*, 'Chal. Rep.' pl. xxii. fig. 4; 'Kerguelen Polyzoa,' *Busk.*
3. „ Honolulensis, *Busk*, 'Chal. Rep.' pl. xxii. fig. 12.

Only one species (No. 1, the type of the genus) is given by Mr. Hincks in his 'Brit. Mar. Polyzoa.'

Genus 67. Porella, *Gray*

=Porella, *Hincks*, *Smitt* (*pars*), *Gray*, 'Brit. Mus. Radiata.'
=Eschara (*pars*), *Sars.*, *Busk*, *Alder*, *Smitt*
=Hemischara and Lepralia, *Norman* & *Busk.*

'Zoarium erect, ramose, cylindrical, or sub-compressed, or crustaceous and adnate. A median oral avicularium within the primary mouth, with a semi-orbicular or sub-triangular mandible.'—*Chal. Rep.* p. 149.

1. Porella lævis, *Fleming* (*Hincks*, 'Brit. Mar. Polyzoa,' p. 334).
Var. subcompressa, *Hincks*, 'Chal. Rep.' pl. xx. fig. 3.

The only form described by Mr. Busk, who says 'that the difference between this and the usual cylindrical form of the northern *Porella lævis* is sufficient to mark it as a distinct variety.' *Loc.*: Cape de Verde.

Several British species of *Porella* are described by Mr. Hincks, and the list is added to in his descriptions of foreign *Cheilostomata*. 'Throughout this very natural group,' says Mr. Hincks ('Brit. Mar. Polyzoa,' p. 321), 'there is a striking uniformity, not only in the characters of the adult cell, but also in the course of its development; and the study of it has done more than most things to convince me that in this section of the Polyzoa we cannot safely regard the mere erect and branching habit as a generic criterion.' In further remarks Mr. Hincks points out many peculiarities of structure in the several species to which he directs attention.

α. Zoarium incrusting.

2. Porella concinna, *Busk*, 'Brit. Mar. Polyzoa,' p. 323, pl. xlvi.
Var. α, Belli, *Dawson* (*id.*, pl. xlvi. fig. 6).
„ *β*, gracilis, *Hincks* (*id.*, fig. 9).
Loc.: *var. α*, Shetland and Gulf of St. Lawrence.
3. „ minuta, *Norman*, *op. cit.* p. 326, pl. xxix. figs. 1, 2; pl. xxxvi. figs. 6, 8
= (?) Lepralia chilopora, *Manzoni.*

β. Zoarium incrusting, or erect and unilamellate.

4. Porella struma, *Norman*, *op. cit.* p. 329, pl. xxxix. figs. 3, 5
=Hemeschara *id.*, *Norman.*
Loc.: Shetland (rare); Bergen.

γ. Zoarium erect; branches compressed.

5. Porella compressa, *Sowerby*, *op. cit.* p. 330, pl. xlv. figs. 4, 7, and woodcut, p. 322.

δ. *Zoarium erect; branches cylindrical.*

6. Porella lævis, *Fleming*, *op. cit.* p. 334, pl. xlvii. figs. 10, 11.
Range: from Shetland to Arctic Sea.

The above are all British species.

7. Porella nitidissima, *Hincks*, 'Ann. Mag. Nat. Hist.' July 1880, pl. x. fig. 2. *Loc.*: Madeira (*Hincks*).
8. „ rostrata, *Hincks*, *op. cit.* Nov. 1880, p. 382, pl. xvii. fig. 5; and 'Annals,' Feb. 1882, p. 89, pl. v. fig. 2. *Loc.*: Australia (*Miss Jelly* and *Miss Gatty*).
9. „ marsupium, *Macgil.*, *op. cit.* Aug. 1881, p. 123, pl. i. fig. 6. *Loc.*: Bass's Straits.
10. „ Form, porifera, *Hincks* ('Annals,' Jan. 1884, pl. iv. fig. 4). *Loc.*: Victoria, *Macgil.*; Bass's Straits; Queen Charlotte Islands.
11. „ major, *Hincks* ('Annals,' Jan. 1884, pl. iv. fig. 5).
12(?). „ argentea, *Hincks* ('Annals,' March 1884, pl. ix. fig. 1). *Loc.*: Queen Charlotte Islands.
13. „ malleolus, *Hincks* ('Annals,' May 1884, p. 361). *Loc.*: Coast of Burmah.

Genus 68. Escharoides, *Smitt.*

'Secondary orifice sinuated below, with an avicularium on one or both sides of the notch.'—*Chal. Rep.* p. 149.

1. Escharoides occlusa, *Busk*, 'Chal. Rep.' pl. xxi. fig. 8.
2. „ verruculata, *Smitt* (sp.), 'Chal. Rep.' p. 150 = Cellepora *id.*, *Smitt*, 'Florid. Bryozoa.'

Only two species are described by Mr. Hincks in his 'British Marine Polyzoa,' 1880:—

4. Escharoides rosacea, *Busk*, *op. cit.* p. 336, pl. xlvii. figs. 5–9. *Loc.*: Orkney; Shetland; Norway; Spitzbergen.
5. „ quincuncialis, *Norman*, *op. cit.* p. 339, pl. xv. fig. 7. *Loc.*: Deep water, in The Minch.

Genus 69. Smittia, *Hincks*

= Escharella, *Smitt* (not Escharella, *Gray* or *D'Orb.*), Smittia, *Hincks*, 'Ann. Mag. Nat. Hist.' 1879.

'Zoarium erect, bi- or uni-laminar, or crustaceous, free or adnate. Primary orifice entire, with an internal median denticle. Secondary orifice canaliculate, usually inclosing a median avicularium.'—*Chal. Rep.*, p. 150.

(a). *Bilaminar (escharan).*

1. Smittia tenuis, *Busk*, 'Chal. Rep.' pl. xx. fig. 1.

(b). *Unilaminar, erect or crustaceous (hemischaran).*

2. Smittia Smittiana, *Busk*, 'Chal. Rep.' pl. xvii. fig. 2.
3. „ marsupialis, *Busk*, 'Chal. Rep.' pl. xviii. fig. 1.
4. „ transversa, *Busk*, 'Chal. Rep.' pl. xviii. fig. 7.
5. „ marionensis, *Busk*, 'Chal. Rep.' pl. xviii. fig. 6 = Lepralia *id.*, *Busk*, 'Brit. Mus. Cat.'
6. „ Jacobensis, *Busk*, 'Chal. Rep.' pl. xix. fig. 7.

(c). *Adnate (lepralian).*

7. Smittia oratavensis, *Busk*, 'Chal. Rep.' pl. xxii. fig. 1.
(?) S. marmorea, *Hincks*, 'Brit. Mar. Polyzoa,' p. 350.
8. ,, stigmatophora, *Busk*, 'Chal. Rep.' pl. xxii. fig. 6.
9. ,, graciosa, *Busk*, 'Chal. Rep.' pl. xxii. fig. 13.
(?) Porella concinna, *var.* β, gracilis, *Hincks*.

Several species are described in the 'British Marine Polyzoa' and in the 'Contributions' of Mr. Hincks.

10. Smittia Landsborovii, *Johnston*, 'Brit. Mar. Polyzoa,' p. 341, pl. xlviii. figs. 6–9. Widely distributed.
Var. α, crystallina, *Norman* (pl. xxxvi. fig. 2). *Loc.*: The Minch, Shetland; Antrim.
Var. β, porifera, *Smitt* (p. 344). *Loc.*: South Devon; Arctic Seas.
Var. γ, purpurea, *Hincks*, 'Annals,' Aug. 1881. *Loc.*: Bass's Straits; Victoria, Australia.
11. ,, reticulata, *Macgil.* 'Brit. Mar. Pol.' p. 346, pl. xlviii. figs. 1–5. *Loc.*: Various British localities; Bass's Straits: Victoria, Australia.
12. ,, affinis, *Hincks*, *op. cit.* p. 348, pl. xlix. figs. 10, 11. *Loc.*: Start Bay, South Devon.
13. ,, cheilostomata, *Manzoni*, *op. cit.* p. 349, pl. xlii. figs. 7, 8 =Lepralia *id.*, *Manzoni*. *Loc.*: Guernsey; South Devon; Hastings.
14. ,, marmorea, *Hincks*, *op. cit.* p. 350, pl. xxxvi. figs. 3–5. *Loc.*: Cornwall; Guernsey.
15. ,, Bella, *Busk*, *op. cit.* pl. xlii. figs. 9, 10. *Loc.*: Shetland = Lepralia *id.*
16. ,, trispinosa, *Johnston*, *op. cit.* p. 353, pl. xlix. figs. 1–8. *Loc.*: Several British, and widely distributed geographically.
Mr. Hincks describes several varieties in 'Annals,' May 1884, pp. 361, 362, pl. xiii. figs. 7, 7*a*.
Var. α, Jeffreysi, *Norman*. *Loc.*: Dogger Bank (*T. Hincks*).
17. ,, galeata, *Busk*. *Loc.*: Madeira.
18. ,, nitida, *Verrill*. ('Annals,' Feb. 1881, p. 159, pl. ix. figs. 5, 5*a*). *Loc.*: North America (*Verrill*); Africa (*Miss Jelly*).
19. ,, plicata, *Smitt* = Cellepora plicata, *Smitt*.
20. ,, spathulifera, *Hincks*, 'Annals,' Jan. 1884, pl. iv. fig. 3. *Loc.*: Houston Stewart Channel ('Polyzoa of Queen Charlotte Islands').
Var. munita, *Hincks*.
,, spathulata, *Smitt*.
form bimucronata, *Hincks*.

Genus 70. Mucronella, *Hincks*.

'Brit. Mar. Polyzoa,' p. 360.

'Zoarium erect and bi- or uni-laminar, or crustaceous and unattached, or adnate. Orifice mucronate in front.'—*Chal. Rep.*, p. 155.

a. Bilaminar (escharan).

1. Mucronella contorta, *Busk*, 'Chal. Rep.' pl. xx. fig. 9
   = Eschara *id.*, *Busk*, 'Brit. Mus. Cat.' p. 89, pl. cviii. figs. 1-3.
2. " pyriformis, *Busk*, 'Chal. Rep.' pl. xx. fig. 5.

β. Unilaminar, erect or crustaceous, unattached (hemischaran).

3. Mucronella quadrata, *Busk*, 'Chal. Rep.' pl. xviii. fig. 5; and pl. xvii. fig. 8.
4. " delicatula, *Busk*, 'Chal. Rep.' pl. xviii. fig. 2.
5. " rostrigera, *Busk*, 'Chal. Rep.' pl. xix. fig. 2.
6. " bisinuata, *Smitt*, 'Chal. Rep.' pl xix. fig. 5
   = Escharella *id.*, 'Florid. Bryozoa,' p. 59.
7. " castanea, *Busk*, 'Chal. Rep.' pl. xix. fig. 6.
8. " magnifica, *Busk*, 'Chal. Rep.' pl. xviii. fig. 3.

γ. Adnate (lepralian).

9. Mucronella canalifera, *Busk*, 'Chal. Rep.' pl. xxii. fig. 2.
   ? Phylactella (sp.)
   = Lepralia Mangueville, *Busk*, 'Quart. Jour. Micr. Soc.' vol. xiii. p. 284. This form differs from *Lepralia* (*Phylactella*) *labrosa*, and also from *L.* (*Phylactella*) *collaris*—in the one case in the absence of an internal denticle, and in the other in the presence of oral spines and the absence of punctu-ration on the oœcium.
10. " tricuspis, *Hincks*, 'Chal. Rep.' pl. xxii. fig. 3; and *Hincks*, 'Ann. Mag. Nat. Hist.' 1881.
11. " simplicissima, *Busk*, 'Chal. Rep.' pl. xxii. fig. 5. Probably an adnate variety of No. 2.
12. " ventricosa, *Busk* (Lepralia *id.*, 1861, *var.* multispinata, *Busk*)
   = (?) Mucronella Peachii, *var.* octodentata, *Hincks*, 'Brit. Mar. Polyzoa.'

I think it best to give, in addition to the above, the *Mucronellæ* as worked out by Mr. Hincks both in his 'British Marine Polyzoa' and also in his 'Contributions.'

The genus *Mucronella* 'is equivalent in part to the *Discopora* of Smitt, but not of Fleming, who originated the name for a species belonging to a totally different section of the Polyzoa (the *Cyclostomata*), with which it is still connected in the slightly modified form *Discoporella*.'—*Hincks*, 'Brit. Mar. Polyzoa,' p. 360.

a. Without avicularia.

13. Mucronella Peachii, *Johnst.* ('Brit. Mar. Polyzoa,' p. 360, pl. l. figs. 1–5; pl. li. figs. 1, 2).
   Var. a, labiosa, *Busk*, pl. li. fig. 1. *Loc.*: Belfast Bay; Guernsey.
   Var. β, octodentata, *Norman*, pl. li. fig. 2. *Loc.*: Shetland.

14. Mucronella ventricosa, *Hassall*, *op. cit.* pl. l. figs. 6–8
= Lepralia arrecta, *Reuss*, Miocene.
Var. connectans, *Ridley*, 'Polyzoa of Franz Josef's Land.'
15. „ variolosa, *Johnst.* 'Brit. Mar. Polyzoa,' p. 366, pl. li. figs. 3–7.
16. „ laqueata, *Norman*, *op. cit.* pl. li. fig. 8. *Loc.*: Shetland; The Minch; Antrim; Bergen; Arctic Seas.
17. „ abyssicola, *Norman*, *op. cit.* pl. xxxviii. figs. 1, 2. *Loc.*: Shetland; Gulf of St. Lawrence.
18. „ macrostoma, *Norman*, *op. cit.* pl. xxxviii. figs. 3, 4. *Loc.*: Shetland Seas; On the Falmouth-Lisbon Cable, between N. lat. 47° 58′ and 47° 35′, and in W. long. 7° 6′.

β. With a lateral avicularia.

19. Mucronella coccinea, *Abildgard*, *op. cit.* pl. xxxiv. figs. 1–6.
Var. a, mamillata, *Hincks*. *Loc.*: Coast of Antrim.
20. „ pavonella, *Alder*, *op. cit.* pl. xxxix. figs. 8–10.
These are the whole of the British species; some of them, such as Nos. 13, 14, 15, and 19, have a very wide range.
21. „ simplex, *Hincks*, Polyzoa for Barrent's Sea, 'Annals,' Oct. 1880, p. 280, pl. xv. fig. 7.
22. „ (?) tubulosa, *Hincks*, *op. cit.* Nov. 1880, p. 383, pl. xvii. fig. 7. *Loc.*: Australia.
23. „ porosa, *Hincks*, *op. cit.* Aug. 1881, p. 124, pl. i. fig. 5. *Loc.*: Off Curtis Island (Polyzoa Bass's Straits); Singapore or the Philippines (*Miss Jelly*).
24. „ teres, *Hincks*, *op. cit.* pl. ii. fig. 5. Allied to the Brit., No. 14, *ante*. *Loc.*: Off Curtis Island.
25. „ spinosissima, *Hincks*, *op. cit.* pl. iii. fig. 3. *Loc.*: Off Curtis Island.
Var. major, *Hincks*, 'Polyzoa of Queen Charlotte Islands,' *op. cit.* Jan. 1884, pl. iii. fig. 3.
26. „ tricuspis, *Hincks*, *op. cit.* Aug. 1881, p. 125, pl. iii. fig. 1. *Loc.*: Off Curtis Island.
27. „ vultur, *Hincks*, *op. cit.* Aug. 1882, pl. viii. fig. 2. *Loc.*: Australia.
28. „ diaphana, *Macgil.*
Var. armata, *Hincks*, *op. cit.* pl. viii. fig. 3. *Loc.*: New Zealand.
29. „ præstans, *Hincks*, *op. cit.* pl. viii. fig. 1. *Loc.*: Australia.
30. „ rotundata, *Hincks*, *op. cit.* pl. viii. fig. 5. *Loc.*: Singapore or Philippines (*Miss Jelly*).
31. „ prælucida, *Hincks*, *op. cit.* Jan. 1884, pl. iv. fig. 1.
32. „ prælonga, *Hincks*, *op. cit.* pl. iv. fig. 2. *Loc.*: Houston Stewart Channel.
33. „ bicuspis, *Hincks* (?)
34. „ mucronata, *Hincks* (?)

Mr. Hincks gives very full details of the special features of the

Mucronellæ described in his various papers, especially so in describing the species in Captain Warren's collection from Bass's Straits, and Dr. Dawson's from the neighbourhood of Queen Charlotte Islands.

Genus 71. Aspidostoma, *Hincks.*

'Zoarium dimorphous, uni- or bi-laminar; erect, solid, rising from a contracted calcareous base, or expanded and foliaceous. Zoœcia with the front depressed in the centre and the sides tumid. Mouth quite at the summit of the depressed area, concealed under the tumid border, on which above the mouth is a penthouse-like, usually bifid, projection. The mouth arched above, straight below, and protected in front by a broad shield-like plate or mucro which is continued downwards for some distance within the zoœcium.'—*Chal. Rep.* p. 161.

1. Aspidostoma giganteum, *Blainv.*, 'Chal. Rep.' pl. xxxiii. fig. 3
   =Eschara gigantea, *Blainv.*, 'Brit. Mus. Cat.' p. 91
   =Aspidostoma crassum, *Hincks*, 'Ann. Mag. Nat. Hist.' Feb. 1881.
2. „ crassum, *Hincks*, 'Annals,' Feb. 1881, p. 160, pl. x. figs. 6, 6*a*. *Loc.*: Patagonia and the Falkland Islands.

§ 2. *Primary mouth notched or sinuated below.*

Genus 72. Schizoporella, *Hincks*, 'Brit. Mar. Polyzoa.'

'Zoarium erect and bi- or uni-laminar, or crustaceous and unattached, or adnate. Lower lip with a median notch. Operculum pedunculate or contracted below.'—*Chal. Rep.* p. 162.

α. *Bilaminar* (*escharan*).

1. Schizoporella furcata, *Blainv.*, 'Chal. Rep.' pl. xxi. fig. 5.

β. *Unilaminar* (*hemischaran*).

2. Schizoporella nivea, *Busk*, 'Chal. Rep.' pl. xvii. fig. 1.
3. „ longispinata, *Busk*, 'Chal. Rep.' pl. xvii. fig. 2.
4. „ auriculata (?), *Hassall.*
   Var. alba, *Busk*, 'Chal. Rep.' pl. xix. fig. 1.
5. „ Jacksoniensis, *Busk*, 'Chal. Rep.' pl. xix. fig. 3.
6. „ tenuis, *Busk*, 'Chal. Rep.' pl. xx. fig. 10.

γ. *Adnate* (lepralian).

7. Schizoporella elegans, *D'Orb.* = (?) Escharina *id.*, 'Voy. en Amér. Mérid.'
   (?) Lepralia squamoidea, *Reuss & Manzoni*, 'Castrocaro.'
8. „ marsupifera, *Busk*, 'Chal. Rep.' pl. xxii. fig. 14.
9. „ Cecillii, *Aud.* (sp.), 'Chal. Rep.' p. 166; and *Hincks*, 'Brit. Mar. Polyzoa,' p. 262.
10. „ circinata, *Macgil.* = Lepralia, *id.*, *Macgil.*, 'Nat. Hist. Vict.' and 'Chal. Rep.' p. 166, woodcut.
11. „ triangula, *Hincks*, 'Annals,' 1881; 'Chal. Rep.' p. 167.

In addition to the above list of forms described by Mr. Busk from the 'Challenger' collection, no fewer than fifty-two species and varieties have

been described by Mr. Hincks, in his 'British Marine Polyzoa' and in his Contributions in the 'Annals and Mag. Nat. History,' under the family name Myriozoidæ.

a. *Avicularia with a pointed mandible, generally lateral.*

12. Schizoporella unicornis, *Johnst.*, 'Brit. Mar. Polyzoa,' p. 238, pl. xxxv. figs. 1–5.
Form ansata, *Johnst.* *Loc.*: form *ansata*: Greenland; Bergen. The form *unicornis* widely distributed.

13. „ spinifera, *Johnst.*, *op. cit.* pl. xxxv. figs. 6–8. *Loc.*: Not so widely distributed as No. 12.

14. „ Alderi, *Busk*, *op. cit.* pl. xxxvi. figs. 9, 10. *Loc.*: Shetland; Hammerfest; Bergen; Southern Norway.

15. „ vulgaris, *Moll.*, *op. cit.* pl. xxxvii. fig. 7; pl. xv. figs. 5, 6. *Loc.*: Polperro, S.W. of; Antrim; Hastings; Birterbuy Bay; Naples; Madeira.

16.[1] „ simplex, *Johnst.*, *op. cit.* pl. xxxv. figs. 9, 10. *Loc.*: Sana Island; Antrim; Belfast Bay; South Devon (rare); Guernsey; Hastings; Northern Hebrides; Unst, Shetland; Peterhead and Wick.

17. „ linearis, *Hassall*, *op. cit.* pl. xxxviii. figs. 5–10; pl. xxiv. fig. 1.
Var. α, hastata, *Hincks*, pl. xxxiii. fig. 10.
„ β, mamillata, *Hincks.*
„ γ, nitida, *Hincks.*
„ δ, crucifera, *Norman.*
Loc.: Several are given by Mr. Hincks, p. 251.

18. „ sanguinea, *Norman*, *op. cit.* pl. xxxix. figs. 6, 7 = Hemeschara, *id.*, *Norman.*
Loc.: Guernsey; Naples; Cornwall; Florida.

19. „ cristata, *Hincks*, *op. cit.* pl. xl. fig. 6, 6*a*. *Loc.*: Hastings (*Miss Jelly*).

b. *With a rounded or spatulate avicularia, lateral or median.*

20. Schizoporella biaperta, *Michelin*, *op. cit.* pl. xl. figs. 7–9.
Form eschariformis, *Waters*
≐ (?) Hippothoa divergens, *Smitt.*
Loc.: *var.* divergens, Guernsey; Hastings; Algiers; Florida. *Var.* biaperta, Spitzbergen; Kara Sea; Florida. *Var.* eschariformis, Bruccoli (fossil).

21. „ armata, *Hincks*, *op. cit.* pl. xli. figs. 7, 8. *Loc.*: Polperro, S.W.; Algiers.

(4.) „ auriculata, *Hassall* (see Busk's list, No. 4) (*Hincks*, *op. cit.* pl. xxix. fig. 3–9).
Var. α, ochracea, *Hincks* = Lepralia auriculata, *var.* Leontiniensis, *Waters.*
Var. β, cuspidata, *Hincks.*
Loc.: Very widely distributed and common.

22. „ umbonata, *Busk*, *op. cit.* pl. xxiv. fig. 2. *Loc.*: Shetland (Barlee).

[1] See No. 53, p. 98.

23. Schizoporella discoidea, *Busk, op. cit.* pl. xxx. figs. 8, 9
= Alysidota conferta, *Busk*, 'Rep. Brit. Assoc.'
Loc.: Shetland; Antrim; Hastings; Guernsey; Madeira; Algiers; Birterbuy Bay.

c. *Usually without avicularia.*

24. Schizoporella sinuosa, *Busk, op. cit.* pl. xlii. figs. 1–6.
Var. α, armata, pl. xlii. fig. 2.
Loc.: Shetland; W. coast Scotland; Spitzbergen, and other Arctic localities; Gulf of St. Lawrence.

(9.) „ Cecilii, *Aud., op. cit.* pl. xliii. fig. 6. *Loc.*: Jersey; Guernsey; Algiers; (?) Adriatic; Naples; Cornwall; Australia (*Miss Jelly*).

25. „ cruenta, *Norman, op. cit.* pl. xxx. fig. 5. *Loc.*: Shetland (rare); Peterhead (rare); Orkney; Channel Islands; Nova Zembla; Greenland.

26. „ hyalina, *Linn., op. cit.* pl. xviii. figs. 8–10.
Var. α, cornuta, pl. xlv. fig. 2 (Australia; California; New Zealand, &c.)
„ *β*, incrassata.
„ *γ*, tuberculata.
Loc.: Widely distributed. Coasts of Great Britain and Ireland; and, as regards geographical range, cosmopolitan.

d. *Avicularia on a distinct area above the cell.*

27. Schizoporella venusta, *Norman, op. cit.* pl. xxx. fig. 6
= Gemellipora glabra, forma, striatula, *Smitt.*
Loc.: Off Guernsey; Florida.

The above are the whole of the British species given by Mr. Hincks.

(11.) Schizoporella triangula, *Hincks*, Polyzoa Bass's Straits, Liverpool Address, *Hincks*, April 1881.

28. „ tumida, *Hincks*, Polyzoa Bass's Straits, Ibid.

29. „ acuminata, *Hincks*, Polyzoa Bass's Straits, Ibid.

30. „ insignis, *Hincks*, 'Annals,' Aug. 1881, p. 134, pl. v. fig. 10. 'As bearing on the morphological relations' (of the special pore of the Microporellidæ) 'of this portion of structure, an observation by Mr. Ridley ("Annals," June 1881, p. 448, &c.) is interesting. He has noticed a Myriozoidan stage in the development of a Porinidan cell, in which the pore had not yet become isolated, but was connected by a gap with the orifice.'—*Hincks*, 'Annals,' Aug. 1881, p. 135. *Loc.*: Africa.

31. „ incrassata, *Hincks* ('Annals,' Feb. 1882, p. 124, pl. v. figs. 1, 1*a*). *Loc.*: Africa, on coral (*Miss Jelly*).

32. „ levata, *Hincks* (*ibid.*, pl. v. fig. 4). *Loc.*: Australia, on weed (*Miss Jelly*).

33. „ aperta, *Hincks* (*ibid.*, pl. v. fig. 3). *Loc.*: Singapore (*Miss Jelly*).

34. Schizoporella crassilabris, *Hincks* ('Annals,' June 1883, pl. xviii. fig. 1).
35. ,, crassirostris, *Hincks* (*ibid.* pl. xviii. fig. 3).
36. ,, longirostrata, *Hincks* (*ibid.* pl. xvii. fig. 4).
37. ,, insculpta, *Hincks* (*ibid.* pl. xvii. fig. 5, 5*a*).
38. ,, tumulosa, *Hincks* (*ibid.* pl. xviii. fig. 2).
39. ,, pristina, *Hincks* (*ibid.* pl. xvii. fig. 6).
40. ,, maculosa, *Hincks* (*ibid.* No figure).
41. ,, torquata, *D'Orb.* ('Annals,' March 1884, pl. ix. fig. 2).
= S. Dawsoni, *Hincks*, 'Annals,' June 1883.
Loc.: From 34 to 41, 'Polyzoa of Queen Charlotte Islands.'
42. ,, cinctipora, *Hincks* ('Annals,' March 1883, p. 200, pl. vii. fig. 3). *Loc.*: New Zealand (*Miss Jelly*).
43. ,, biserialis, *Hks.* ('Annals,' March 1885, pl. vii. fig. 3) = S. arachnoides, *Macgil.* *Loc.*: New Zealand.
44. ,, cribrillifera, *Hincks* (*ibid.*, pl. viii. fig. 5). *Loc*: Cook's Straits, New Zealand.
45. ,, scintillans, *Hincks* (*ibid.*, pl. ix. fig. 7). *Loc.*: New Zealand.
46. ,, lucida, *Hincks* (*ibid.*, pl. ix. fig. 5). *Loc.*: Australia, on weed.
(10.) ,, circinata, *Macgil.* (*ibid.*, pl. vii. fig. 1). *Loc.*: Napier, New Zealand; Victoria, *Macgil.*
47. ,, argentia, *Hincks* (*ibid.*, pl. ix. fig. 6, and 'Annals,' Feb. 1881, p. 158, pl. ix. fig. 66*a*). *Loc.*: Africa, on coral.
(17.) ,, linearis, *Hassall.*
Form, quincuncialis, *Hincks*, 'Annals,' Feb. 1881, p. 158, pl. ix. fig. 3. *Loc.*: Ceylon (*Miss Jelly*).
48. ,, fissurella, *Hincks.*
49. ,, latisinuata, *Hincks.*
50. ,, subsinuata, *Hincks.* } 'Annals,' 1884, vol. xiv. pp. 280,
51. ,, biturrita, *Hincks.* } 281. Port Phillip Heads.
52. ,, marsupium, *Ridley*, 1881 = S. Ridleyi, *Macg.*
53. ,, Johnstoni, *Quelch* = S. simplex, *Johnston* (non *D'Orb.*), 'Annals,' xiii. 1884, pp. 51 and 215–217.

Genus 73. Gephyrophora, *Busk.*

'Zoarium dimorphous, either erect and irregularly branched, and cylindrical, with the zoœcia disposed round an imaginary axis, or decurrent, loosely incrusting, and unilaminar. Zoœcia completely immersed, flat in front, parted by septal ridges. Surface beneath the epitheca finely reticulate. Primary orifice arcuate, with the lower border slightly sinuated, afterwards transversely oblong. A prominent avicularian process on each side of the orifice, the two eventually inarching and forming a bridge in front of it.'—*Chal. Rep.* p. 167.

Gephyrophora polymorpha, *Busk*, 'Chal. Rep.' pl. xxxi.

Genus 74. Myriozoum, *Donati.*

'Zoarium erect, branched, continuous; branches cylindrical, obtuse, or oviform. Surface punctured or reticulate. Avicularia, when pre-

sent, immersed, and usually placed near the orifice, either above, below, or on one or both sides. Orifice notched or sinuate, or caniculate below.'—*Chal. Rep.* p. 168.

§ 1. *Myriozoa typica.*

1. Myrizoum truncatum, *Donati.*
2. „ subgracile, *D'Orbigny.*
3. „ coarctatum, *Sars.*

Referred to and placed as above in the 'Challenger Report' (p. 169), but not otherwise described.

§ 2. *Myriozoa dubia.*

1. Myriozoum honolulense, *Busk*, 'Chal. Rep.' pl. xxv. fig. 2
2. „ immersum, *Busk*, 'Chal. Rep.' pl. xxv fig. 4.
3. „ simplex, *Busk*, 'Chal. Rep.' pl. xxv. fig. 1.
4. „ Marionense, *Busk*, 'Chal. Rep.' pl. xxiii. fig. 6.

Genus 75. Haswellia, *Busk*

= Myriozoum (sp.), *Haswell.*

Zoarium composed of short cylindrical branches, spreading in all directions dichotomously at very open angles. Zoœcia disposed verticellately, and more or less irregularly quincuncial, with a produced tubular or sub-tubular and bifid, or simply thickened peristome, supporting on each side a small avicularium with a pointed subtriangular mandible. Primary mouth clithridiate, with an operculum of corresponding form.

1. Haswellia australiensis, *Haswell*, 'Chal. Rep.' pl. xxiv. fig. 9
   = Myriozoum australiense, 'Proc. Lin. Soc. N. S. Wales,' 1880.
2. „ auriculata, *Busk*, 'Chal. Rep.' pl xxiv. fig. 10.

Genus 76. Tessarodoma, *Norman*

= Pastulopora (pars), *Sars*; Quadricellaria, *Sars*; *Alder*
= Anarthropora, *Smitt*; Tessarodoma, *Norman.*
Porina (part), *Hincks.*

Tessaradoma boreale, *Busk*, 'Chal. Rep.' p. xxiv. fig. 8
= Pastulopora gracilis, *Sars*
= Quadricellaria gracilis, *Sars*
= Onchopora borealis, *Busk*
= Anarthropora borealis, *Smitt*
= Tessarodoma gracile, *Norman*
= Tessarodoma boreale, *Smitt*
= Porina borealis, *Hincks.*

Genus 77. Gemellipora, *Smitt.*

Gemellipora (pars), *Smitt*, 'Florid. Bryozoa.'

'Zoarium erect and ramose, or crustaceous and adnate. Mouth elongate, pyriform, with an articular notch on either side below. Operculum of corresponding pyriform shape. A median immersed avicularium, either above or below the mouth.'—*Chal. Rep.* p. 176.

α. Erect and ramose (escharan).

1. Gemellipora glabra, *Smitt*, 'Chal. Rep.' pl. xxv. fig. 3
= G. glabra (forma typica), 'Florid. Bryoz.'

β. Adnate (lepralian).

2. Gemellipora cribritheca, *Busk*, 'Chal. Rep.' pl. xxxiii. fig. 5.

The following four genera, established by Mr. Hincks for British species of Marine Polyzoa, are not accepted—or only partly accounted for—in the classification of Mr. Busk :—

Genus 78. Umbonula, *Hincks*.

'Zoœcia with a primary orifice, sub-orbicular or sub-quadrangular, lower margin slightly curved inwards, peristome not elevated, no secondary orifice; a prominent umbo (? avicularian cell) immediately below the mouth, supporting an avicularium. Zoarium (in British species) incrusting.'—*Brit. Mar. Poly.* p. 316.

Umbonula verrucosa, *Esper.* (Umbonella, text, p. 316), pl. xxxix. fig. 1, 2. *Loc.*: Several British; Roscoff; Adriatic (rare); Greenland.

Genus (78?). Phylactella, *Hincks*
= Lepralia (*Auctt*, part) = Alysidota (sp.), *Busk*.

'Zoœcia with the primary orifice more or less semicircular, the lower margin usually dentate; peristome much elevated, not produced or channelled in front. No avicularia. Zoarium (in British species) incrusting.'—*Brit. Mar. Polyzoa*, p. 356.

1. Phylactella labrosa, *Busk* (*Hincks*, pl. xliii. fig. 12). *Loc.*: Antrim; Shetland; S. Devon; Hastings; Wick; Cornwall.
2. ,, collaris, *Norman*, *op. cit.* pl. xliii. fig. 3. *Loc.*: Hebrides, Shetland; Guernsey; Hastings; Antrim.
3. ,, exima, *Hincks*, *op. cit.* pl. xlix. fig. 11. *Loc.*: Antrim; off the Deadman; Shetland.
4. ,, lucida, *Hincks*, 'Annals,' July 1880, pl. x. fig. 4. *Loc.*: Madeira.

Genus 79 (?). Palmicellaria, *Alder*.

'Zoœcia with the primary orifice orbicular, or ranging from semicircular to semi-elliptical; the peristome elevated around it, so as to form a secondary orifice, and carried out in front into a projecting palmate or mucronate process, with an avicularium on its inner aspect. Zoarium (in the British species) erect and ramose, or (?) lamellate.'—*Brit. Mar. Polz.* p. 378.

1. Palmicellaria elegans, *Alder*, *op. cit.* pl. xxx. figs. 7–9. *Loc*: Zetland Seas; Loch Fyne.
2. ,, Skenie *Ell.* and *Sol.*, *op. cit.* pl. lii. figs. 1–4.
   Var. α, bicornis, *Busk* (Crag form).
   ,, *β*, foliacea. *Loc.*: Wick.
   ,, *γ* tridens, *Busk*. Norway.
3. ,, lorea, *Alder* ('Brit. Mar. Pol.' pl. lii. figs. 5, 6). *Loc.*: Shetland.
4. ,, (?) cribraria, *Johnston*. (Provisionally placed.) *Loc.*: Berwick Bay, *Johnston*.

Family **Myriozoidæ**, *Hincks.*

Genus 53 (?). Rhynchopora, *Hincks.*

'Zoœcia with the primary orifice transversely elliptical, lower margin slightly sinuated; secondary orifice sub-orbicular, with a mucro on the lower margin and an uncinate process immediately above it within the mouth. Zoarium (in the British species) incrusting.'—*Brit. Mar. Pol.* p. 385.

1. Rhynchopora bispinosa, *Johnston, op. cit.* p. xl. figs. 1–5. *Loc.*: Berwick Bay; South Devon (abundant): Cornwall; Guernsey; Shetland; Caithness (very rare); Mazatlan; Adelaide.
2. „ longirostris, *Hincks*, 'Annals,' May 1881. Captain Warren's collection.

Genus 54 (?). Schizotheca, *Hincks.*

'Brit. Mar. Polyzoa,' p. 283.

1. Schizotheca fissa, *Busk*, 'Brit. Mar. Pol.' p. 284, pl. xli. figs. 1–3.
2. „ divisa *Norman, op. cit.* p. 385, pl. xli. figs. 4–6.
3. „ fissurella, *Hincks*, 'Annals,' 1882, 'Polyzoa of Queen Charlotte Islands.'

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Genus 54*. Mastigophora, *Hincks.*

(See Genus 62 of Report, and 'Brit. Mar. Pol.' *Hincks*, p. 278.)

1. Mastigophora Dutertrei, *Aud.* 'Brit. Mar. Pol.' p. 279, pl. xxxvii. figs. 1, 2.
2. „ Hyndmani, *Johnston, op. cit.* p. 281, p. xxxvii. figs. 3–6.
3. „ „ *var.* ensiformis (MS. ? *Miss Jelly*).
4. „ „ „ porosa, *Pourtalès.*

Family XXII. **Adeoneæ**, *Busk*, 'Chal. Rep.' p. 177.

'Zoarium erect or (rarely) incrusting, affixed either by a more or less flexible or unjointed, radicate, chitino-calcareous peduncle, or immediately attached to some flexible body, either with or without a contracted base. Bilaminar except when incrusting; foliaceous, expanded, and fenestrate, or branched, or lobate, or entire. Cells of two or usually three kinds, zoœcial, oœcial, avicularian. No oœcia of the usual type. On the front a median pore, usually simple and circular, sometimes irregularly fimbriate, or represented by a depressed perforated areola. Usually one or more sessile avicularia on the front. In the oœcial cells the pore in most cases is sub-oral, or placed immediately below the mouth, and usually a minute avicularium on each side. The wall of the zoœcial cells is punctate or entire; that of the oœcial always punctate.'—*Loc. cit.* p. 177.

This important family group is founded upon well marked structural peculiarities:—

1. The existence of three distinct forms of cells.
2. The entire absence of oœcia of the usual type.
3. The presence of a median pore or its equivalent.
4. In the presence of avicularian cells, which are wholly converted into 'vicarious avicularia.'

Mr. Busk enumerates several other important characters, but one deserves special notice :—

'It consists in the circumstance that in the entire group the avicularian mandibles, both large and small, always exhibit a projecting point or articular process at each end of the base, into or close to which the erector muscles are attached. To which may be added that, so far as I have noticed, the occlusor muscle of the mandible is always single instead of consisting of two bands as usual.'—*Busk*, *loc. cit.* p. 178.

The genus *Adeona* is the subject of a monograph by Dr. Kirchenpauer ('Ueber die Bryozoa, Gattung Adeona,' Hamburg, 1879), in which he enumerates eight forms which are regarded by him as species. These are as follows :—

1. Adeona foliacea or follifera, *Lamx.* and *Lamk.*
2. ,, intermedia, *Kirchenpauer.*
3. ,, macrothyris, *Kirchenpauer.*
4. ,, arborescens, *Kirchenpauer.*
5. ,, grisea, *Lamouroux.*
6. ,, cellulosa, *Macgillivray.*
7. ,, albida, *Kirchenpauer.*
8. ,, Wilsoni, *Macgillivray*, which has been added since the monograph was written.

Besides these published Mr. Busk says that he is acquainted from direct observation with five or six others 'that I have not been able to identify with any of the foregoing, and which will be included in a projected memoir on the genus, which I hope to be able shortly to prepare.'

9. Adeona appendiculata (n. sp.) Australia.
10. ,, Gattyæ (n. sp.) South Africa.
11. ,, lancifera (n. sp.) Australia.
12. ,, vulga (n. sp.) Australia.
13. ,, microthyris (n. sp.) Australia.
14. ,, lycopodioides (n. sp.) South Atlantic, *Busk*, 'Chal. Rep.' p. 179.

The first only appears in the 'Challenger' collection.

Genus 80. Adeona, *Lamouroux.*

Adeona, *Lamx.*, *Lamk.*, *Kirchenpauer.*
Dictyopora, *Macgillivray*, 'Nat. Hist. Vict.' Decade V.

'Zoarium erect, foliaceous, expanded, flabellate or lobate, fenestrate or entire, usually supported on a flexible or sub-flexible, chitino-calcareous, nearly jointed stem, composed of radicle tubes incrusted with calcareous matter and attached by spreading radical fibres. If without a stem generally attached to a flexible support.'—*Chal. Rep.* p. 181.

Adeona appendiculata, *Busk*, 'Chal. Rep.' pl. xxxiii. fig. 6, woodcuts, 47, 48, p. 182.

Genus 81. Adeonella, *Busk.*

'Zoarium erect, very variously branched or lobate, attached by a contracted base, or pedicle, often containing radical fibres, and affixed usually on a more or less flexible support.'—*Chal. Rep.* p. 183.

Only eight species of *Adeonella* occur in the 'Challenger' collection, but Mr. Busk has furnished a list of recent forms which he would be

inclined to include in the sub-genus as described above. In all probability there are many fossil forms that should be included in this group.

1. Adeonella tuberculata (n. sp.) = Eschara lichenoides, 'Brit. Mus. Cat.' (Not Milne-Edw.)
2. „ feugensis, *Busk.*
3. „ sulcata, *Milne-Edw.*
4. „ arcuata, *Busk*, MS.
5. „ lichenoides, *Milne-Edw.*
6. „ falciformis, *Busk*, MS.
7. „ megapora, *Busk*, MS.
8. „ dolichostoma (n. sp.), MS.
9. „ natalensis (n. sp.), MS.
10. „ crassa (n. sp.), MS.
11. „ Pallasii, *Heller.*
12. „ Helleri (n. sp. ?), MS.
13. „ dispar, *Macgillivray.*
14. „ mucronata, *Macgillivray.*
15. „ fissa, *Hincks.*
16. „ subsulcata, *Smitt.*
17. „ polymorpha, *Busk*, pl. xxi. figs. 1*a*, 2*a*, 3, 3*a*, not figs. 1 and 2, woodcut, p. 183.
18. „ platalea, *Busk*, 'Chal. Rep.' pl. xxi. figs. 4, 4*a*, excluding the branched figure, woodcut, p. 184
    = Eschara platalea, *Busk*, 'Brit. Mus. Cat.'
    = (?) Eschara hexagonalis, *Haswell*, 1881.
19. „ intricaria, *Busk*, 'Chal. Rep.' pl. xxi. fig. 2, woodcuts, 51 and 53, p. 185.
20. „ atlantica, *Busk*, 'Chal. Rep.' pl. xx. fig. 7, woodcut, 54, p. 186.
21. „ regularis, *Busk*, 'Chal. Rep.' pl. xx. fig. 2, and woodcut, 55, p. 186.
22. „ distoma (?) *Busk*, 'Chal. Rep.' p. 187, woodcuts, 56, 57
    = (?) Eschara coscinophora, *Reuss, Stolica & Manzoni*
    = (?) Porellina coscinophora, *D'Orb.*
    Lepralia distoma, *Busk*, 'Quart. Jour. Mic. Soc.'
    „ distoma, *Busk.*
23. „ *Var.* imperforata, *Busk*, 'Chal. Rep.' pl. xx. fig. 4.
24. „ pectinata, *Busk*, 'Chal. Rep.' p. 189, woodcut.

Genus 82. Reptadeonella, *Busk.*

'Challenger Report.' Referred to on pages 178 and 180, but not described. The genus will include—

1. Reptadeonella violacea
   = Lepralia *id.*
2. „ innominata (probably).

And several fossil forms.

Family XXIII. **Celleporidæ.**

Johnston, 'Brit. Mus. Cat.' *Hincks.*
Escharidæ (*pars*), *D'Orbigny.*
Myriozoidæ (*pars*), *Smitt.*

'Zoœcia urceolate, erect or sub-erect, irregularly heaped together, and often forming several superimposed layers.'—*Chal. Rep.* p. 190.

Genus 83. Cellepora.

Fabric., *Linn*, &c., 'Brit. Mus. Cat.' *Johnst.*, *Hincks.*
Celleporaria, *Lamx.*, *Reuss*, *D'Orb.*

'Zoarium multiform, lamellar and incrusting, partially adnate or free, or erect and attached by a thick base, massive and irregularly branched, solid or hollow, or in the shape of small parasitic housiform or discoid growths. Zoœcia in the older portions more or less erect or vertical, very irregularly disposed or heaped together. Orifice entire or sinuated in front, with or without internal denticles. A pre-oral rostral process (sometimes aborted), usually supporting an avicularium; very generally interspersed avicularia.'—*Challenger Rep.* p. 190.

Mr. Busk might well speak of this as a 'multiform and perplexing genus,' and I question very much that had it not been for the close study which he has given to the chitinous parts—of which he gives two plates—whether he would have been able to furnish such admirable details of species. Mr. Busk divides the genus into four sections:—

§ 1. Operculum sub-orbicular or semicircular, with a nearly straight lower border; avicularian mandibles with a short median columella.[1]

§§ *a. Lobate, branched, or massive.*

1. Cellepora hastigera, *Busk*, 'Chal. Rep.' pl. xxix. fig. 1, pl. xxxv. fig. 8.
2. „ tuberculata, *Busk*, 'Chal. Rep.' pl. xxviii. and pl. xxxv. fig. 7.
3. „ albirostris, *Smitt*, 'Chal. Rep.' pl. xxx. fig. 7, pl. xxxv. fig. 3
   = Discopora *id.* (forma typica), 'Florid. Bryoz.'
   (?) = Cellepora bispinata, *Busk*, 'Brit. Mus. Cat.' p. 87.
4. „ aspera, *Busk*, 'Chal Rep.' pl. xxviii. fig. 6.
5. „ columnaris, *Busk*, 'Chal. Rep.' pl. xxix. fig. 11, pl. xxxv. fig. 16.
6. „ honolulensis, *Busk*, 'Chal. Rep.' pl. xxix. fig. 5, and pl. xxxv. fig. 15.
7. „ imbellis, *Busk* (?) 'Chal. Rep.' pl. xxix. fig. 7, and pl. xxxv. fig. 20.
8. „ Jacksoniensis, *Busk*, 'Chal. Rep.' pl. xxx. fig. 10, pl. xxxv. fig. 9.
9. „ polymorpha, *Busk*, 'Chal. Rep.' pl. xxx. fig. 11.

§§ *β. Incrusting.*

10. „ apiculata,[2] *Busk*, 'Chal. Rep.' pl. xxix. fig. 2, pl. xxxv. fig. 12.
11. „ samboangensis, *Busk*, 'Chal. Rep.' pl. xxx. fig. 7 and pl. xxxv. fig. 10.
12. „ discoidea, *Busk*, 'Chal. Rep.' pl. xxx. fig. 8, pl. xxxv. fig. 1.

[1] 'This character,' says Mr. Busk, 'seems to be confined to species belonging to the southern hemisphere, as it is not present in the Mediterranean *Cellepora sardonica* and *Cellepora digitata*.'

[2] Figure from a bad specimen; chitinous parts all right.

13. Cellepora tridenticulata, *Busk*, 'Chal. Rep.' pl. xxix. fig. 3 and pl. xxxv. fig. 17.
14. „ vagans, *Busk*, 'Chal. Rep.' pl. xxix. fig. 10 and pl. xxxv. fig. 11.
15. „ mammillata, *Busk*, 'Brit. Mus. Cat.' p. 87.
    Var. atlantica, *Busk*, 'Chal. Rep.' pl. xxxv. figs. 4, 5, and 13.

§ 2. Operculum pedunculate or produced downwards, usually with an articular notch on each side. No median columella in the mandibles.

§§ *a. Lobate, branched, or ramose.*

16. Cellepora rudis, *Busk*, 'Chal. Rep.' pl. xxviii. fig. 7 and pl. xxxvi. fig. 7.
17. „ solida, *Busk*, 'Chal. Rep.' pl. xxix. fig. 12.
18. „ pustulata, *Busk*, 'Chal. Rep.' pl. xxviii. fig. 8.
19. „ cylindriformis, *Busk*, 'Chal. Rep.' pl. xxx. fig. 9, and pl. xxxvi. fig. 9.
20. „ Simonensis, *Busk*, 'Chal. Rep.' pl. xxix. fig. 9; pl. xxxvi. fig. 8, p. 200.
21. „ Eatonensis, *Busk*, 'Chal. Rep.' pl. xxix. figs. 4, 6, 8; and pl. xxxvi. figs. 3–5.
22. „ ovalis, *Busk*, 'Chal. Rep.' pl. xxviii. fig. 5; and pl. xxxv. fig. 6.

§§ *β. Pisiform.*

23. „ bicornis, *Busk*, 'Chal. Rep.' pl. xxx. figs. 1 and 12; and pl. xxxvi. figs. 13, 15.
24. „ bilabiata, *Busk*, 'Chal. Rep.' pl. xxx. fig. 2.
25. „ signata, *Busk*, 'Chal. Rep.' pl. xxx. fig. 3; and pl. xxxvi. fig. 14.
26. „ conica, *Busk* (?), 'Chal. Rep.' pl. xxviii. fig. 10; and pl. xxxvi. fig. 1
    = (?) Cellepora avicularis, *Smitt*, 'Florid. Bryozoa.'
27. „ ansata, *Busk*, 'Chal. Rep.' pl. xxx. fig. 4; and pl. xxxvi. fig. 17.
28. „ canaliculata, *Busk*, 'Chal. Rep.' pl. xxx. fig. 5; and pl. xxxvi. fig. 16.
29. „ bidenticulata, *Busk*, 'Chal. Rep.' pl. xxx. fig. 6; and pl. xxxvi. fig. 6.
29.* „ *Var.* subæqualis, *Busk*, 'Chal. Rep.' pl. xxxvi. fig. 11, chitinous parts.
30. „ granum, *Hincks*, 'Ann. Mag. Nat. Hist.' 1861, 'Chal. Rep.' p. 205, pl. xxxvi. fig. 10.
31. „ tubulosa, *Hincks* (sp.), 'Chal. Rep.' p. 205
    = C. Costarii, *var.* tubulosa, *Hincks*, 'Brit. Mar. Pol.,' 'Chal Rep.,' woodcut, p. 205.

In his 'British Marine Polyzoa' and Contributions in the 'Annals,' Mr. Hincks describes other species whose names are not found in the above list.

Cellepora pumicosa, *Linn.*, 'Brit. Mar. Pol.' p. 398, pl. liv. figs. 1–3. Widely distributed.
„ ramulosa, *Linn.* (*op. cit.* pl. lii. figs. 7–9).

Cellepora dichotoma, *Hincks* (*id.* pl. lv. figs. 1–6).
Var. a, attenuata, *Alder* (*id.* figs. 7–10).
„ avicularis, *Hincks* (*op. cit.* pl. liv. figs. 4–6).
„ tubigera *Busk* ('Crag Pol.'); *Hincks*, pl. liv. figs. 7–9.
„ armata, *Hincks* (*op. cit.* pl. liv. figs. 10–13).
„ Costazii, *Aud.* (*op. cit.* pl. lv. figs. 11–14).
Var. a, tubulosa, *Hincks* (see above, No. 31).
„ albirostris, *Smitt* (see No. 3, above), Hincks's 'Polyzoa of Bass's Straits.'
„ lævis, *Haswell* (Hincks's 'Polyzoa of Bass's Straits').

Family XXIV. **Selenariadæ**, *Busk.*

'Brit. Mus. Cat.' pl. i. p. 97.

'Zoarium orbicular or irregular in outline, convex on one side, plane or concave on the other; in the mature state probably free, often with a foreign particle, central or eccentric, on the concave face. Zoœcia immersed, flustrine.'—*Chal. Rep.* p. 206.

1. Genus Cupularia, *Lamouroux.*
2. Genus Lunularia, *Lamouroux.*

Genus 84. Cupularia, *Lamx.*

Cupularia, *Lamx.*, *Busk*, 'Brit. Mus. Cat.' p. 97.
Lunulites (pars), *Defrance* and *Auctt.*

1. Cupularia guineensis, *Busk*, 'Brit. Mus. Cat.' p. 98; 'Chal. Rep.' pl. xiv. fig. 6.
2. „ monotrema, *Busk*, 'Chal. Rep.' pl. xiv. fig. 5.
3. „ Owenii, *Gray*, 'Chal. Rep.' p. 207
= Lunulites *id.*, *Gray*
= Cupularia *id.*, *Busk*, 'Brit. Mus. Cat.'
= „ denticulata, *Conrad*
= Lunulites alveolatus (?), *S. Wood.*
4. „ Loweii, *Busk*, 'Brit. Mus. Cat.'
5. Stellata, *Busk* „ „
6. „ pyriformis, *Busk* „ „
7. „ canarienses, *Busk* „ „
8. „ Johnsonii, *Busk* „ „

Genus 85. Lunularia, *Lamouroux*

= Lunulites, *Lamx.*, 1821, 'Brit. Mus. Cat.'

'Zoœcia disposed in series, radiating from the centre and bifurcating as they advance towards the border; the vibracularia lying in linear series, alternating with those of the zoœcia. The chitinous vibraculum usually bifid or trifid at the extremity.'—*Chal. Rep.* p. 208.

Lunularia capulus, *Busk*, 'Brit. Mus. Cat.' p. 100; 'Chal. Rep.' p. 208, pl. xiv. fig. 7.
incisa, *Hincks*, 'Annals,' Aug. 1881, p. 127, pl. iv. figs. 1–3
= (?) Conescharellina, *D'Orb.*
gibbosa, *Busk*, 'Brit. Mus. Catalogue.'
cancellata, *Busk* „ „
philippinensis, *Busk* „ „

β. Part II.

Sub-order II. Cyclostomata, *Busk*

= Tubuliporina, *Milne-Edw.*, *Johnst.*, *Hagenow*, &c.
= Auloporina, Myrioporina (part), *Ehrnberg*
= Cenoporina (part), *Bronn*
= Centrifuginea (part), *D'Orbigny*

Group 1. Radicellata, *D'Orbigny.*

Zoarium erect, articulated, attached by radical tubes.

Family I. **Crisiidæ**, *Busk.*

'Crag Polyzoa,' p. 92, 1859; *Hincks*, 'Brit. Mar. Polyzoa'; *Busk*, 'Cyclostomata, 'Brit. Mus. Cat.' pl. iii.

In Professor Smitt's papers on the order Cyclostomata ('Scandinavian Bryozoa'), the family Crisiidæ is divided into two genera, *Crisidia*, Milne-Edwards, and *Crisia*, Lamouroux; and Mr. Busk follows this arrangement in the third part of his 'British Museum Catalogue' (Cyclostomata, 1875). Mr. Hincks in his 'British Marine Polyzoa,' and in his subsequent writings, disallows the genus *Crisidia*, Milne-Edwards, and I think wisely so. In his Cyclostomatous part of the 'Bay of Naples Bryozoa,' previous to the publication of Mr. Hincks's work ('Annals,' April 1879), Mr. A. W. Waters also adopted this arrangement. Mr. Hincks, however, divides the group into two series, α and β.

Genus 1. Crisia, *Lamx.* (part)

= Crisia, *Fleming*, *Blainville*, *Milne-Edwards* (part), *Johnston*, *D'Orbigny*, *Busk*, *Hincks*, *Waters*.
Falcaria (part), *Oken*.

Zoœcia in a single series or in two alternate series (*Hincks*). Oœcia irregularly placed (*Busk*).

1. Crisia cornuta, *Linnæus* = Sertularia *id.*, *Linn. Sys.* 1316
= Falcaria *id.*, *Oken*, *Gray*
= Crisia setacea, *Couch* = (?) Crisidea *id.*, *Sars*
= Unicellaria cornuta, *Blainv.*
Hincks, p. 419, pl. lvi. figs. 1–4; Busk, p. 3, pl. i. figs. 1–10.

Localities: Widely distributed round our coast.
Geographical Distribution: Mediterranean; Bay of Naples (rare); Scandinavia; Finland; Greenland; coasts of France; Houston-Stewart Channel; Virago Sound (common), *Hincks*.

2. Crisia cornuta, *var.* β, geniculata *Busk.* Without spines
= C. geniculata, *Milne-Edw.*, *Johnst.*, Sars
= C. cornuta (*var.*), *Smitt* (*sine cornibus*)
= Filicrisia geniculata, *D'Orb.*
Localities: Both shores of the British Channel.
Geogr. Distrib.: Roscoff; Mediterranean; Bahusia; Norway.

3\. Crisia eburnea *Linn.*= Sertularia *id. Linn.*
= Crisia eburnea, authors generally.
(?) C. Haueri, *Reuss* (*fide* Manzoni)
= Crisia (group A), Vine, 5th ' Rep. Foss. Polyzoa,' 1884.
Localities: Generally distributed, British seas.
Geogr. Distrib.: North and Arctic Seas; St. Lawrence; Labrador; St. George's Banks; California; Fiji Islands; New Zealand; Australia; Virago Sound (Queen Charlotte Islands); Madeira; Mediterranean.

4\. „ eburnea, *var. α*, aculeata, *Hassall.*
British localities: Kingstown Harbour; Brighton (*Hassall*); Antrim; Ayrshire; Shetland (see *Hincks*, pp. 420–1 pl. lvi. figs. 5, 6, woodcut, fig. 21, p. 416. *Busk*, ' Cyclostomata,' p. 4, pl. ii. figs. 1, 2, pl. v. figs. 1, 2, 5).

5\. „ eburnea, *var. β*, producta, *Smitt.*
The position of this form is doubtful. Norman refers it to *eburnea*; Smitt places it between the two. Mr. A. W. Waters (' Bay of Nap. Bry.') ranks it as a distinct species, and remarks: ' As there are connecting links between this and *cornuta* it might be called *C. cornuta* var. *producta*, or even *C. geniculata*, var. *producta*.' In his description, however, Mr. Waters says the ' ovicell axillary.' Mr. Hincks, ' Brit. Mar. Pol.' places it as above. Mr. Busk (' Cyclostomata,' p. 10) says, ' Probably only a variety of *C. cornuta* (*vide* pl. i. fig. 3); it does not appear to have any character in common with *C. eburnea*.'
Locality: Shetland, 100 to 170 fathoms.
Geogr. Distrib: Naples littoral (rare); Scandinavia; Nova Zembla, 5 to 10 fathoms.

6\. „ denticulata, *Lamk.*= Cellaria *id. Lamk.*
= C. luxata, *Flem.*, *Blainv.*, *Johnst.*, *Couch*
= Crisia and Cellaria arctica, *Sars*
= (?) Crisia attenuata, *Heller* (*fide Hincks*).
Hincks, p. 422, pl. lvi. figs. 7–9.
Busk, p. 4, pl. ii. figs. 3, 4, pl. iii. figs. 1–6, pl. iv. figs. 1–4.
Waters (' Bay of Nap. Bry.' ' Ann.,' Ap. 1879), p. 269 pl. xxii. fig 2.
Localities, Brit.: Very generally distributed.
Geogr. Distrib.: Roscoff; Adriatic (*Heller*); Madeira; South Africa (*Busk*); Norway; Spitzbergen; Kara Sea; Grand Manan (Busk says?); Houston Stewart Channel (*Hincks*); Franz Joseph Land (*S. O. Ridley*).

7 „ fistulosa, *Heller* (non *Busk*) Adriatic
= (?) C. eburnea (pars *Smitt*), *A. W. Waters.*
= C. Haueri, *Reuss* (*A. W. Waters*, ' Bry. Bay Nap.')
= (?) C. eburnea, *Manzoni* (see No. 3, ' Bry. Bay Nap.,' *Waters*, pl. xxiii. fig. 3. ' Prof. Heller's comparison with *C. geniculata* would be very inappropriate for the *C. fistulosa* of Busk, *A. W. Waters.*
Loc.: Naples; Adriatic? (*Heller*).

8. Crisia fistulosa, *Busk* (non *Heller*), 'Cyclostomata,' pl. via. figs. 1, 2.
Loc.: Lissa; Lagorta; Adriatic? *Busk*, pl. via. figs. 1, 2, p. 5 ('Cyclostomata').
9. " elongata M.-Edw. = C. attenuata, *Heller* (*Waters*) = Cellaria elongata, M.-Edw., *D'Orb.*
Loc.: Adriatic (*Hincks*); Naples, 40 fathoms (*Waters*); Red Sea? (M.-Edw.); Algoa Bay. *Busk*, pl. iv. figs. 5, 6, p. 5. *Waters*, pl. xxiii. fig. 1, p. 269.
10. " elongata, *var.* angustata, *Waters*, pl. xxiii. fig. 4. 'Bry. Bay Nap.,' Ap. 1879, p. 269.
There seems to be much difference of opinion respecting *Crisia elongata* and its varieties. My own specimens from South Africa differ from Mediterranean specimens even from the same depths as Mr. Waters's deep and shallow water forms. Mr. Waters gives the following synonyms, which, at present, I cannot accede to: *C. fistulosa*, Busk; (?) *C. Edwardsii*, Reuss; (?) *C. Edwardsii*, Manzoni.
11. " Edwardsiana, *D'Orb.*, *Busk*, p. 5, pl. ii. figs. 5–8.
= (?) Bicrisia Edwardsiana, *D'Orb.*, 1852
= Crisidia Edwardsiana, *D'Orb.*, 1839, 'Voy. dans. l'Amér.'
Geogr. Distrib.: Coasts of Patagonia, *D'Orb.*; Tierra del Fuego, *Darwin*; New Zealand, *Dr. Sinclair*; Australia, *Macgil.*

Mr. Busk says: 'D'Orbigny's figure represents the zoœcia as much longer and more slender than his own specimens; but he has retained his name because he has but little doubt about the identity of his own and D'Orbigny's species.'

12. Crisia eburneo-denticulata *Smitt* (MS.), *Busk*, pl. vi.
= Crisia eburnea (*var.*) *Smitt.*
Loc.: Spitzbergen, 70–96 fathoms.
13. " acropora, *Busk*, pl. v. figs. 3, 4, *Id.*, 'Voy. of Rattles.,' vol. i. p. 351.
Loc.: Bass's Straits, 47 fathoms.
14. " margaritacea, *Busk*, pl. vi. *b*, fig. 1
= C. denticulata, *Busk*, 'Voy. of Rattles.'
Loc.: Australia, 'Voy. of Fly,' *Jukes.*
15. " Sinclairensis, *Busk*, pl. iv. figs. 7–11. *Loc.*: Coast of Patagonia (*Dr. Sinclair*).
15*. " Holdsworthii, *Busk*, pl. vi. *a*, fig. 2. *Loc.*: Pearl-oyster Bank, Ceylon (*Holdsworth*).
16. " conferta, *Busk*, pl. vi. *a*, fig. 5. *Loc.*: Cape Verd Islands (H.M.S. *Herald*).
17. " tubulosa, *Busk*, pl. vi. *a*, figs. 3, 4. *Loc.*: Cape Verd Islands (H.M.S. *Herald*).

These are the whole of the species of *Crisia* illustrated by Mr. Hincks, Mr. Busk ('Cyclostomata'), and Mr. Waters ('Bay of Nap. Bry.'). Mr. Busk, however, gives a list of other recent forms noticed by authors (see 'Cyclos.' pp. 7 to 9).

18. Crisia sertulariodes, *D'Orb.* = Probiscina *id. Aud.* *Loc.*: Red Sea (?). May be C. fistulosa, *Heller.*
19. „ patagonica, *D'Orb.*, 'Voy. Amér. Mérid.' *Loc.*: Patagonia.
20. „ sinensis, *D'Orb.*, 'Pal. Fr.' = (?) C. elongata, *M.-Edw.* *Loc.*: Hongting.
21. „ martinicensis, *D'Orb.*, 'Pal. France.' *Loc.*: Martinique.
22. „ californica, *D'Orb.*, 'Pal. France.' *Loc.*: Lower California.
23. „ punctata, *D'Orb.* (?) = *C. Sinclairensis* (15). *Loc.*: Ile de Venado, Mer Vermeille, California.
24. „ attenuata, *Heller.* *Loc.*: Adriatic (*Lesina*).
25. „ recurva, *Heller.* *Loc.*: Adriatic (*Lesina*).
26. „ setosa, *Macgil.* ('Australian Pol.' p. 16). *Loc.*: Australia.
27. „ biciliata, *Macgil.* Having seen a specimen of this species I think it ought to be kept distinct from C. Edwardsiana, *D'Orb.*
28. „ producta, *Smitt.* *Loc.* (*Smitt*): Scandinavia (as C. eburnea, *Norman*); Shetland.
29. „ tenuis, *Macgillivray.* *Loc.*: Australia.

Group II. Incrustata, *D'Orb.*

Zoarium calcareous, continuous, not divided by corneous joints, or furnished with radicle tubes; erect and attached by a contracted base, or recumbent and immediately adnate, either wholly or in part.

This division is accepted by Mr. Busk in his catalogue of the Cyclostomata ('Brit. Mus.' pt. iii.), and in nearly the same words, only the arrangement is different from that of Mr. Hincks.

Family II. **Tubuliporidæ.**

'Zoarium entirely adherent, or more or less free and erect, multiform, often linear, or flabellate or lobate, sometimes cylindrical. Zoœcia tubular, disposed in contiguous series or in single lines. Oœcium an inflation of the surface of the zoarium at certain points or a modified cell.'—*Hincks*, 'Brit. Mar. Polyzoa,' p. 424.

1. Stomatopora, *Bronn.*
2. Tubulipora, *Lamarck.*
3. Idmonea, *Lamouroux.*
4. Entalophora, *Lamx.*
5. Diastopora, *Lamx.* (part).

Genus 2. Stomatopora, *Bronn.*

'Brit. Mus. Cat.' *Busk*, as *Alecto*, pp. 23, 24.
'Brit. Marine Polyzoa,' *Hincks*, as *Stomatopora*, p. 424.
'Fifth Rep. Foss. Polyzoa,' 1884, as *Stomatopora*, which see for description and fossil species.

1. Stomatopora granulata, *M.-Edw.*
 = Alecto *id.*, *Johnston* (pt.)
 = Stomatopora incrassata, *D'Orb.*
 = (?) Alecto parasita, *Heller.*
 Localities.: Several British from Shetland to Cornwall.
 Geogr. Distrib.: Roscoff (*Joliet*); Bergen, *Hincks*, pl. lvii. figs. 1, 2; *Busk*, pl. xxxii. fig. 1.

2. Stomatopora major, *Johnston*, *Hincks*, pl. lviii. and pl. lxi. fig. 1
= Alecto *id.*, *Busk*, pl. xvii. figs. 3–5; pl. xvi. fig. 3 (?)
= (?) Tubulipora trahens, *Couch*
= (?) ,, repens, *S. V. Wood* = Alecto, *Busk*, 'Crag Pol.' Other synonyms given by Busk with (?).
Localities: Several Brit.: Cornwall; Northumberland; Antrim; Isle of Man; Shetland; Guernsey.
Geogr. Distrib.: Bergen; Roscoff (*Hincks*); Scandinavian and Arctic seas (*Busk*).

3. ,, dilatans, *Johnst.* (*Hincks*, pl. lvii. figs. 3, 3*a*)
= Alecto *id.*, *Busk*, pl. xxxii. fig. 2
= (?) Diastopora repens (part), *Smitt*
= Alecto *id.*, *Manzoni*, 'Castrocaro'
= S. dilatans, *Vine*, 'fifth Brit. Assoc. Rep.' 1884, for other particulars.
Localities: Several northern British.
Geogr. Distrib.: Roscoff; Scandinavian coast, great depths.

4. ,, Johnstoni, *Heller* (*Hincks*, pl. lix. fig. 1; pl. lx. figs. 1, 1*a*)
= Criserpia *id.*, *Heller*
= (?) Alecto granulata, *Johnst.*
Localities: Guernsey; coast of Antrim.
Geogr. Distrib.: Mediterranean; Adriatic (*Heller*).

5. ,, expansa, *Hincks*, pl. lxii. fig. 1
= (?) Proboscina ramosa, *D'Orb.*
= Idmonea cenomana, *D'Orb.*
Locality: On dead shells, Isle of Man (*Hincks*).

6. ,, incurvata, *Hincks*, pl. lxiv. figs. 6–8.
Localities: Coast of Antrim (abundant); Hebrides; off Caithness; Guernsey.

7. ,, diastoporides, *Norman* (*Hincks*, pl. lxiii. figs. 3, 4)
=Alecto *id.*, *Norman*, Shetland, 'B. A. Rep.' 1867.
Localities: Shetland, 70–110 fathoms; Wick; off the Maiden lighthouses, Co. Antrim, 62–72 fathoms.
Geogr. Distrib.: Gulf of St. Lawrence; off Hare Island, Baffin's Bay, 175 fathoms ('Valorous' dredging).

8. ,, compacta, *Norman* (*Hincks*, pl. lxiii. figs. 1, 2).
Localities: Hebrides; The Minch; Shetland.
(Sub-genus Proboscina, *Smitt*)

9. ,, incrassata, *Smitt* (*Hincks*, pl. lix. figs. 2, 3)
=Tubulipora, *id.*, *Smitt*
=Alecto retiformis, *Hincks*, 'Supplement Devon and Cornwall Polyzoa.'
= (?) Filisparsa incrasata, *D'Orb.*
Localities: Several Brit.: Salcombe Bay; Cornwall; Guernsey; Shetland.
Geogr. Distrib.: Bahusia, in great depths; Spitzbergen; Nova Zembla; Kara Sea.

10. Stomatopora deflexa, *Couch* (*Hincks*, pl. lvii. fig. 4)
=Tubulipora *id.*, *Couch*
=Pustulipora *id.*, *Johnst.*, *Hincks*, (?) *Heller.*
Localities: Polperro; Mevagissey Bay; Wick; Peterhead; Shetland.
Geogr. Distrib.: Roscoff (*Joliet*).

11. „ fungia, *Couch* (*Hincks*, pl. lvii. figs. 5, 6)
=Tubulipora penicillata, *Johnst.*, *Landsb.*, *Alder*, *Hincks* (not *Fabric.*).
Localities: From Eddystone Lighthouse to Deadman Point; Polperro; Torbay; Wick and Peterhead; Banff.
Geogr. Distrib.: Finmark, 50 fathoms; Greenland; Hamilton's Inlet, Labrador.
Mr. Busk, in his 'Cyclostomata,' p. 26, pl. xxxii. fig. 3, describes and figures this species as Tubulipora fungia, *Couch.*

12. „ fasciculata, *Hincks*, p. 441, pl. lix. figs. 4, 5.
Locality: Coast of Antrim.

Genus 3. Tubulipora, *Lamk.*

Johnston, *Milne-Edw.*, *D'Orbigny*, *Busk.*
Ceriopora (pt.), *Hagenow*; Phalangella (sp.), *Gray.*
Obelia (sp.), *Lamx.*; Reptotubigera, *D'Orb.*
Tubulipora, *Vine*, 'Fifth Brit. Assoc. Rep.,' which see for several fossil species.

1. Tubulipora lobulata, *Hassall* (*Hincks*), pl. lxi. figs. 4, 5
=T. serpens (*pars*), *Busk*, 'Brit. Mus. Cat.' pl. iii.
Localities: British: Dublin Bay; Isle of Man; Torbay; Hastings. Scotland: Shetland.
Geogr. Distrib.: Scandinavian Coasts.

2. „ flabellaris, *Fabric.*, *Hincks*, pl. lxiv. figs. 1–3
=T. phalangea, *Couch* (*Busk*, 'Cat.' pt. iii. pl. xxiii.)
Localities: Cornwall; South Devon; Whitehead, Co. Antrim; Shetland.
Geogr. Distrib.: Bahusia; Bergen; Spitzbergen; Greenland; (?) South Labrador; Adriatic.

3. „ fimbria, *Lamk.* (*Hincks*, pl. lx. figs. 3, 3*c*)
=T. flabellaris, *Johnst.* (*Busk*, 'Cat.' pt. iii. pls. xxiv., xxv.)
Localities: Wick and Peterhead; Northumberland; Shetland.
Geogr. Distrib.: Greenland; Labrador; Gulf of St. Lawrence; Spitzbergen; Nova Zembla.

In his 'Brit. Mus. Catalogue,' pt. iii. Mr. Busk gives the following as Tubulipora:—

4. Tubulipora ventricosa, *Busk*, pl. xxxii. fig. 4
=T. incrassata, *var. a*, forma erecta, *Smitt; Busk*, 'Quart. Jour. Mic. Soc.' vol. iii. p. 256.
Geogr. Distrib.: W. Greenland (H.M.S. *Sophia*); Arctic and Norwegian seas; Spitzbergen.

5. Tubulipora pyriformis, *Busk*, 'Cat.' pt. iii. p. 27 (no plate).
Geogr. Distrib.: Tasmania.

From other authors (Busk's authority) :—

6. Tubulipora organizans, *D'Orb.*, 'Voy. dans l'Amér. Mérid.' p. 19, pl. ix. figs. 1–3.
Geogr. Distrib.: Falkland Islands.
7. „ dichotoma, *D'Orb.*, *id.*, p. 19, pl. ix. figs. 7, 31.
Geogr. Distrib.: Falkland Islands (? Proboscina).
8. „ malacensis, *D'Orb.*, 'Pal. France,' p. 847.
Geogr. Distrib.: Straits of Malacca.
9. „ capitata, *Hincks*, 'Annals,' Aug. 1881.
10. „ perfragilis, *Hincks*, 'Annals,' March 1884.
11. „ Dawsoni, *Hincks*, pl. ix. fig. 5.
12. „ fasciculifera, *Hincks*, pl. ix. fig. 6.

The above three species (10–12) are described by Mr. Hincks in his paper On the Polyzoa of Queen Charlotte Islands, 'Ann. Mag. Nat. Hist.' March 1884. No. 10 not figured.

Genus 4. Idmonea, *Lamouroux*.

See *Hincks* and *Busk* for synonyms; *Vine*, 'Fifth Brit. Assoc. Report,' for particulars of fossil species and special details.

1. Idmonea atlantica, *E. Forbes*; *Hincks*, pl. lxv. figs. 1–4; *Busk*, 'Brit. Mus. Cat.' pt. iii. pl. ix.
= I. radians, *Van Beneden*.
Var. a, tenuis, *Busk*.
Localities: British: Zetland seas; Outer Haaf; Hebrides.
Geogr. Distrib.: Naples; Hammerfæst (*Sars*); Grotsund; Norway; Frederickshaab; Baffin's Bay (entrance); Nova Zembla; Kara Sea.
Variety: North Atlantic; Florida; Madeira.
2. Idmonea serpens, *Linn.*; *Hincks*, pl. lxi. fig. 23; pl. lx. fig. 2
= Tubulipora serpens, *Busk*, *op. cit.* p. 25, pl. xxii.
Var. a, radiata, *Hincks*.
Localities: Generally distributed. *Var. a*, Cornwall.
Geogr. Distrib.: S. W. France; Mediterranean (*Lamx.*, *Heller*); Naples; Scandinavian Coast, Bahusa to Finmark.

The following are additional species compiled from Mr. Busk and other authorities, 'Cyclostomata,' 'Brit. Mus. Cat.' pt. iii.

3. Idmonea radians, *Lamk.*, *Busk*, *op. cit.* pl. vii. figs. 1–4.
Geogr. Distrib.: Australian seas abundant; New Zealand.
4. „ Milneana, *D'Orb.*, *Busk.*, *op. cit.*
= (?) I. transversa, *Milne-Edw.*
Geogr. Distrib.: Iles Malouines, *D'Orb.*; coast Tierra del Fuego; Patagonia; Chonos Archipelago (*Darwin*).

5. Idmonea contorta, *Busk, op. cit.* p. 12, pl. viii.
   Geogr. Distrib.: Algoa Bay, South Africa.
6. „ notomala, *Busk, op. cit.* pl. xii. a.
   Geogr. Distrib.: Rasel Amousth., Mediterranean (H.M.S. 'Porcupine').
7. „ marionensis, *Busk, op. cit.* pl. xiii. figs. 3, 4; pl. vii. figs. 7, 8 (young state).
   (?) Crisina hocstetteriana, *Stoliz*, and 'Florid. Bryozoa,' *Smitt.*
   Geogr. Distrib.: Marion Island; ? Gulf of Florida; Orakei Bay, Auckland, New Zealand.
8. „ irregularis, *Meneghini, op. cit.* pl. xii.
   Geogr. Distrib.: Adriatic; Dalmatian coast; Mediterranean (H.M.S. 'Porcupine').
9. „ parasitica, *Busk, op. cit.* pl. x. figs. 2, 3.
   Geogr. Distrib.: South Australia.
10. „ gracillima, *Busk, op. cit.* pl. vii. figs. 5, 6.
   Hab.: Atlantic Ocean, 286–322 fathoms (H.M.S. 'Porcupine').

Other recent species noticed by authors (*Busk*):—

11. Idmonea frondosa, *Meneghini.* Adriatic Sea.
12. „ gracilis „ „
13. „ serpula, *Heller* „
   Probably identical with No 11.
14. „ Meneghinii, *Heller.* Adriatic Sea.
15. „ triforis, *Heller.* „
16. „ tubulipora, *Meneghini.* „
17. „ dilatata, *D'Orb.* Ile de Ré.
18. „ angustata, *D'Orb.* Newfoundland.
19. „ rustica, *D'Orb.*
   Geogr. Distrib.: Manilla; Hongkong; Macao; Chasan Archipelago (*D'Orb.*).
20. „ tuberosa, *D'Orb.* Isl. de Basilan
   = (?) I. marionensis, *Busk.*
21. „ canariensis, *D'Orb.* Teneriffe
   = (?) I. gracillima, *Busk.*
22. „ californica, *D'Orb.*
   Geogr. Distrib.: Ile de Venado; Mer Vermeille; California.
23. „ fenestrata, *Busk,* 'Crag Polyzoa.' ? Spitzbergen, 50 fathoms.
24. „ australis, *Macgil.* Australia.

Genus 5. Entalophora, *Lamouroux*

= Pustulopora (part), *Blainv., Milne-Edw., Busk*

= Entalophora, *Vine.* Fifth 'Brit. Assoc. Rep.' for details and fossil forms.

1. Entalophora clavata, *Busk, Hincks,* pl. lxv. figs. 5–8
   = Pustulopora *id., Busk,* 'Crag Polyzoa'
   = Pustulopora deflexa (part), *Hincks.*
   Loc.: Wolf Rock, near Penzance; Torbay; coast of Antrim.

The only British species according to Hincks.

The following species under the name of Pustulopora, *Blainv.*, are given by *Busk* ('Catalogue,' pt. iii.) :—

2. Entalophora delicatula, *Busk*, *op. cit.* p. 20 (no plate).
Geogr. Distrib.: Australia; Cape Capricorn; ? Madeira.
3. „ australis, *Busk*, *op. cit.* pl. xvii. a., left-hand figure.
Geogr. Distrib.: Bass's Straits, 45 fathoms. Australian seas.
4. „ parasitica, *Busk*, *op. cit.* pl. xvii. figs. 1, 2.
Geogr. Distrib.: Bass's Straits; New Zealand.
5. „ proboscidea, *E. Forbes*, *op. cit.* pl. xvii. a., right-hand figure).
Geogr. Distrib.: Shetland seas; Mediterranean; Adriatic; Teneriffe and Canaries; Madeira.
6. „ clavæformis, *Busk*, *op. cit.* pl. xiv.
Geogr. Distrib.: Algoa Bay, South Africa.
7. „ intricaria, *Busk*, *op. cit.* pl. x. figs. 1 (part) and 4.
Geogr. Distrib.: South Australia.

From other authors (*Busk*) :—

8. Entalophora gallica, *D'Orb.*
Geogr. Distrib.: Coast of France; Ile de Ré; Calvados (shore); Newfoundland.
9. „ indica, *D'Orb.* Strait of Malacca.
10. (?) „ orcadensis, *Busk* = Hornera violacea, *Sars.*
Will be referred to again as Hornera.

Genus 6. Diastopora, *Lamx.*

For references to fossil forms and special details, see Remarks, &c., 'Brit. Assoc. Rep. on Fossil Polyzoa,' No. 5, 1884.

Genus Diastopora (part), *Lamx.*

= Patinella (sp.), *Busk*, *Hincks*
= Discosparsa, *D'Orb.*
= Mesenteripora, *Busk*, for foliaceous bilaminate forms.

1. Diastopora patina, *Lamk.* (*Hincks*, pl. lxvi. figs. 1–6). *Busk*, 'Brit. Mus. Cat.' pt. iii. pl. xxix. figs. 1, 2; pl. xxx. fig. 1
= Patinella verrucaria, *Gray*
= Discoparsa marginata, *D'Orb.*
= „ patina, *Heller*
= Diastopora patina, *Smitt.*
Loc.: British, very common, and fairly distributed.
Geogr. Distrib.: Roscoff; S.W. France; Adriatic; North and Arctic Seas; Bahusia; South Norway; Finmark (*Sars*); South Labrador.
2. „ obelia, *Johnst.* (*Hincks*, pl. lxv. figs. 10, 10*a*); *Busk*, *op. cit.* pl. xxvi. *Smitt*; *Heller.*
D. hyalina, *var.* *α*, obelia, *Johnst.*, *Smitt.*
? Berenicea hyalina, *Fleming.*
Localities: British, widely distributed.
Geogr. Distrib.: Guernsey; Jersey; North Sea and Arctic Ocean; Norway; Spitzbergen; Adriatic; Naples.

3. Diastopora sarniensis, *Norman* (*Hincks*, pl. lxvi. figs. 7–9)
= D. hyalina (part), *Smitt.*
Localities: Guernsey and Jersey; Cornwall; Hastings.
Geogr. Distrib.: ? Red Sea or Mediterranean.

4. „ suborbicularis, *Hincks*, pl. lxvi. figs. 11, 11*a*
= D. simplex, *Busk*, *op. cit.* pl. xxix. figs. 3, 4, and 'Crag Polyzoa.'
Localities: South Devon; Isle of Man, &c.
Geogr. Distrib.: Naples; Bahusa; Finmark; Kara Sea; Greenland.

The above four are the whole of the British species given by Mr. Hincks. Mr. Busk gives another species—

5. „ congesta, *D'Orb.*, *Busk*, *op. cit.* pl. xxxi. fig. 5.
Geogr. Distrib.: Mediterranean; African shore (H.M.S. 'Porcupine').

β. Foliaceous and bilaminate.

6. „ (Mesenteripora) meandrina, *Wood.*
The only locality, Greenland.

Family III. **Horneridæ**, *Smitt.*

Hincks, 'Brit. Mar. Polyzoa,' p. 467
= Crisinidæ (pt.), *D'Orb.* ? = Idmoneidæ (pt.), *Busk.*

Genus 7. Hornera, *Lamouroux*
= Siphodictum, *Lonsdale.*

1. Hornera lichenoides, *Linn.*, *Hincks*, pl. lxvii. figs. 1–5
= *Id.*, *Busk*, *op. cit.* pl. xviii. figs. 5, 6
= H. borealis, *Busk*, 'Crag Polyzoa.'
Localities: Shetland; Outer Haaf; Hebrides.
Geogr. Distrib.: Waderöarne, Bahusia; Norway; Nova Zembla; Kara Sea; Greenland; St. George's Banks.

2. „ violàcea, *Sars* (*Hincks*, pl. lxvii. figs. 6–8; pl. lxii. figs. 2, 3); *Busk*, *op. cit.* pl. xviii. figs. 1–4
= Pustulopora orcadensis, *Busk.*

Busk gives the following varieties:—
Var. α, proboscinna, pl. xviii. figs. 1–3.
„ *β*, tubulosa, pl. xviii. figs. 2–4.
Locality (for normal form): Shetland.
Geogr. Distrib.: Arctic Sea; coast of Norway.

Mr. Busk, also in his 'British Museum Catalogue,' part iii., gives the following in addition to the above:—

3. „ frondiculata, *Lamx.*, *op. cit.* pl. xx. figs. 1, 2, 3, 6.
Geogr. Distrib.: Mediterranean; Adriatic, abundant.

4. „ cæspitosa, *Busk*, *op. cit.* pl. xv.
Geogr. Distrib.: Cape Capricorn; Tierra del Fuego.

5. „ pectinata. *Busk*, *op. cit.* p. 18.
Geogr. Distrib.: Madeira.

6. „ tubulosa, *Busk*, *op. cit.* p. 19. Only described, no references or plate.

7. Hornera foliacea, *Macgil.*, *op. cit.* pl. xiii. figs. 1, 2; pl. xix.
= Retihorneri, *id.*, *Busk*, *op. cit.*
Geogr. Distrib.: South Australia.
8. „ robusta, *Macgil.* Australia.

Since the early—and now classical—labours of Mr. Busk on this peculiar genus, much has been added to our knowledge respecting species of the genus, but rather by way of suggestion as to its classificatory position. In the 'Crag Polyzoa,' 1859, *Hornera* takes its place as the first genus in the *Idmoneidæ* of Busk. In his descriptions (p. 95) Mr. Busk speaks of both recent ramose and fenestrate species.

Ramose 1. Hornera frondiculata, *Lamx.*
„ 2. „ borealis (MS.), *Busk.*
„ 3. „ tridactylites (MS.), *Busk.*

The first a Mediterranean form; the second collected on the coast of Norway by Mr. McAndrew; and the third by Mr. Darwin on the shores of Patagonia and Tierra del Fuego, and by Mr. Macgillivray in the Australian seas.

Of the fenestrate kinds Mr. Busk at that time was acquainted with two forms—'apparently distinct species, both of which I believe to be, and one certainly is, Australian. No account of this species, of which very perfect specimens were brought by Mr. Gould from South Australia, has yet been published, although figures of it have been prepared. I propose to call it Hornera Gouldiana' (*Busk*, 'Crag Polyzoa, p. 95). The Hornera borealis of above is the H. lichenoides, *Linn.*, of the Cyclostomata ('Brit. Mus. Cat.' p. 17).

In the 'British Marine Polyzoa' Mr. Hincks established the family Horneridæ for the reception of the two British species already given, remarking that that 'Hornera is connected with the Tubuliporidæ through Idmonea, to which it bears in many points a very close resemblance. It embraces two very characteristic groups, one of which may be represented by H. lichenoides, in which the zoœcia are covered in front by a calcareous crust, which takes the form of wavy longitudinal ridges,' and H. violacea, in which the superficial crust is wanting (*op. cit.* pp. 469, 470).

In remarking on the fossil species of Macgillivray's *Hornera folicea* Mr. Waters ('Quart. Jour. Geol. Soc.' p. 688, vol. xl.) draws attention to the 'transverse tubules' of the species, but his remarks on his sections are too brief for special work. After examining some very fine specimens of the Australian *Hornera* both in the bulk and in section, I may be allowed to say that for other purposes than for the mere description or diagnosis of recent forms these Australian species may be conveniently studied, more especially so if only to dispel the idea of the supposed identity of species of *Fenestella* or *Polypora* with recent *Hornera*. The structure is most peculiar and interesting, whether we select for illustration the superficial features only or the tubular cells with their intervening tubules, as referred to by Mr. Waters.

Family IV. **Lichenoporidæ**, *Smitt.*

Hincks, 'Brit. Mar. Polyzoa,' p. 471
= Discoporellidæ, *Busk*, *op. cit.* p. 30.

Lichenoporidæ, *Vine*, 'Fifth Brit. Assoc. Rep. Foss. Polyzoa' for special details and fossil species.

Genus 8. Lichenopora, *Defranc.*

= Discoporella, *Gray, Busk.*

For other synonyms, see *Hincks* and *Busk.*

a. Colony simple.

1. Lichenopora hispida, *Flem.* (*Hincks*, pl. lxviii. figs. 1–8)
= Discoporella, *id.*, *Busk*, *op. cit.* pl. xxx. fig. 3.
Var. a, Meandrina, *Peach* (*Hincks*, woodcut, p. 475).
,, *β*, *Hincks.*
Localities: South Coast of Britain; Isle of Man; Hebrides; Shetland; St. Andrew's; Northumberland; Guernsey.
Var. a, Shetland, 170 fathoms.
Geogr. Distrib.: Bahusia; Norway; Finmark; Greenland; South Labrador; France.

2. ,, radiata, *Aud.* (*Hincks*, pl. lxviii. figs. 9, 10)
= Discoporella radiata, *Busk*, *op. cit.* pl. xxxiv. fig. 3.
Localities: South Devon; Brixham; Salcombe.
Geogr. Distrib.: Mediterranean; Adriatic; Naples.

3. ,, verrucaria, *Fabric.* (*Hincks*, pl. lxiv. figs. 4, 5)
= Discoporella, *Busk*, *op. cit.* p. xxviii. figs. 2, 3
= (?) Disparsa hispida, *Heller*
= (?) Tubulipora hispida, *Johnston*
Localities: Orkney (*Barlee*); Arran (*Busk*); co. Down (*Hyndman*).
Geogr. Distrib.: Bahusia; Norway; Finmark; Davis' Straits, 100 fath.; Reykiavik; Hamilton's Inlet, Labrador; Assistance Bay, Greenland; Bay of Fundy; St. George's Banks; Nova Zembla; Malotschkin-scharr; Kara Sea.

4. ,, regularis, *D'Orb.* (*Hincks*, pl. lxviii. fig. 11).
= Actinopora *id.*, *D'Orb.*
Locality: Shetland.

The above are the whole of the British species given by Mr. Hincks. The following list is compiled from Mr. Busk's 'Cyclostomata,' and from other authorities, all as *Discoporella* from Mr. Busk.

5. Lichenopora algoensis, *Busk*, *op. cit.* pl. xxviii. figs. 1–4.
Geogr. Distrib.: Algoa Bay, on *Catenicella*.

6. ,, ciliata, *Busk*, pl. xxx. fig. 6.
Geogr. Distrib.: Cape of Good Hope, on *Retepora*; New Zealand, on *Hornera*.

7. ,, Novæ-Zelandiæ, *Busk*, pl. xxx. fig. 2.
Geogr. Distrib.: Chonos Archipelago; Tierra del Fuego; Cape Horn; Chiloe; Tasmania.

8. ,, californica, *D'Orb.*, pl. xxx. fig. 5
=Unicavea, *id.*, *D'Orb.*
Geogr. Distrib.: San Diego, California; off Milva Maura, San Pedro, California.

9. Lichenopora mediterranea, *Blainv.*, *Busk*, pl. xxiv. fig. 4
=Actinopora *id.*, *D'Orb.*, and Unicavea, *id.*, *D'Orb.*
Geogr. Distrib.: Mediterranean.

10. „ Holdsworthii, *Busk*, pl. xxx. fig. 4.
Geogr. Distrib.: Ceylon.

Noticed by *Busk*, but no figures given.

11. „ convexa, *D'Orb.*=Unicavea, *id.*, *D'Orb.*
Geogr. Distrib.: Coast of Calvados.

12. „ Novæ-Hollandiæ, *D'Orb.*=Unicavea, *id.*
Geogr. Distrib.: Bay of Chiens; Marius (? Seal Bay), New Holland.

13. „ complanata, *Meneghina*
= Discosparsa, *id.*, *Heller*
= (?) D. radiata, *Audouin.*
Geogr. Distrib.: Adriatic.

14. „ annularis, *Heller* = (?) L. mediterranea.
Geogr. Distrib.: Adriatic.

15. „ mellevillensis, *D'Orb.*
Geogr. Distrib.: Port Melleville (? Melville).

As *Radiopora* Busk also gives the following:—

16. Lichenopora simplex, *Busk*, pl. xxxiv. fig. 2.
Geogr. Distrib.: Mazatlan.

17. „ cristata, *Busk*, pl. xxxiv. fig. 1.
Geogr. Distrib.: John Adam's Bank; South Atlantic.

Macgillivray describes as follows new species of Discoporella from Port Phillip Heads:—

18. Lichenopora reticulata, *Macgil.* Descriptions of new or little known Polyzoa, 'Roy. Soc. of Victoria,' Dec. 1883, part vi. pl. i. fig. 1.
19. „ pristis, *Macgil.*, *op. cit.* pl. i. fig. 3.
20. „ echinata, *Macgil.*, *op. cit.* pl. i. fig. 4.

The position of the following is doubtful:—

Tennysonia, *Busk*; stellata, *Busk* ('Cyclostomata,' pl. xxxi. fig. 6).

Genus 9. Domopora, *D'Orb.*

For synonyms, &c., see *Hincks*, 'Brit. Mar. Polyzoa'; *Busk*, Cyclostomata, 'Brit. Mus. Cat.' p. iii.

1. Domopora stellata, *Goldfuss*; *Hincks*, pl. lxiii. figs. 10, 11
= Domopora truncata, *Busk*, *op. cit.* pl. xxxi. figs. 1, 2, not Millepora truncata, *Jameson.*
Mr. Hincks gives nine synonyms, Mr. Busk seven synonyms of this species, besides a number of references by both authors.
Localities: Zetland, deep water; Outer Haaf, in 70 to 170 fathoms.
Geogr. Distrib.: Norway (Rasch); Norway from Bergen to Bejan, 40–60 fathoms (*Sars*).

2. Domopora truncata, *Jameson; Hincks*, pl. lxiii. figs. 5–9
= Millepora, *id.*, *Jameson*; not D. truncata, *Busk*.
Locality: Shetland.

As *Defrancia* Busk adds the following:—

3. Domopora lucernaria, *Sars* (*Busk*, pl. xxxiii. fig. 3).
Geogr. Distrib.: Coasts of Norway and Finmark; Spitzbergen; Umenak, Greenland, 250 fathoms; Julian Hafen, 130 fathoms.

Family V. **Frondiporidæ**, *Smitt*.

(See *Busk*, 'Cyclostomata,' p. 37.)

This family is not noticed by Mr. Hincks in his 'British Marine Polyzoa,' but Mr. Busk describes several species, in his 'Cyclostomata,' under two genera:—

1. Genus Fasciculipora, *D'Orb.*
2. „ Frondipora, *Imperato*.

Genus 10. Fasciculipora, *D'Orb.*

= Fangella, *Hagenow; Busk*, 'Crag Polyzoa,' p. 118.

1. Fasciculipora digitata, *Busk*, pl. xxxiii. fig. 1.
Geogr. Distrib.: Cape Capricorn, Australia.
2. „ ramosa, *D'Orb.; Busk*, pl. xxxiii. fig. 2.
(?) Frondipora ramosa, *Hagenow*.
(?) Fangella prolifera, *Hagenow*.
Geogr. Distrib.: South Patagonia, 48 fathoms (*Darwin, D'Orb.*)
3. „ bellis, *Macgil.*, Description of new or little known Polyzoa, 'Roy. Soc. Victoria,' Dec. 1883, No. vi. pl. i. fig. 2.
4. „ fruticosa, *Macgil.*, *op. cit.* pl. i. fig. 6. *Locality*: Port Phillip Heads, Victoria.

Genus 11. Frondipora, *Imperato*.

1. Frondipora reticulata, *Blainv.* (pl. xxi.).
(See Busk for eight synonyms.)
Geogr. Distrib.: Mediterranean, very abundant.
2. „ palmata, *Busk*, pl. xx. figs. 4, 5.
Geogr. Distrib.: Australia. (?)

Species noticed by other authors:—

3. Frondipora verrucosa, *Lamx.; Busk*, p. 39
= Krusensterna *id.*, *Lamx.*
= Frondipora reticulata, *var.* β, *Smitt*.
Geogr. Distrib.: Kamtschatka, Spitzbergen.
4. „ Marsigli, *Blainv.; Busk*, p. 39.
(A very doubtful species.)

Genus Heteropora, *Blainv.*

'Zoarium erect, cylindrical, undivided or branched; surface even, furnished with openings of two kinds—the larger representing the *orifices*

of the cells, and the smaller the *ostioles* or the interstitial canals or tubes.' —*Busk*, 'Crag Polyzoa,' p. 120.

1. Heteropora pelliculata, *Waters*, 'Journ. Roy. Mic. Soc.,' June 1879, p. 391, pl. xv. figs. 1–4, 7. *Locality*: Gulf of Tartary; Isle of Sanghalien; Japan.
2. „ cervicornis, *D'Orb.* = Plethopora *id.* (*op. cit.* p. 392, pl. xv. figs. 9–11). *Locality*: Adelaide.
   Macgillivray describes the same species under a new generic term, *Densipora*, as D. corrugata, *Macgil.*, 'Roy. Soc. Vic.' *Locality*: Queenscliffe; Portland; Warrnambool.
3. „ Neo-Zelanica, *Busk*, 'Linn. Soc. Journal,' 1879, vol. xiv. p. 725, pl. xv. fig. 14. *Locality*: New Zealand.

See also Nicholson, 'On the genus Monticulipora,' Edinb. 1881, pp. 63–78, in which will be found a rather full description of the structure of Recent Heteropora, for the purpose of making comparison with Fossil species of the Monticuliporidæ. Prof. Nicholson gives figures of Recent *Heteropora Neo-Zelanica*, Busk.

List of Synonyms, &c. compiled from Mr. Hincks' 'British Marine Polyzoa' (Index, 1880).—*Cheilostomata.*

Names in the right-hand column adopted by Mr. Hincks' 'British Marine Polyzoa' and also in this Report.

Acamarchis, *Lamk.*, 1816	= Bugula, *Oken*, p. 73.[1]
Geoffroyi, *Aud.*	= Scrupocellaria reptans, p. 73.
Ætea Americana, *D'Orb.*	= Æ. anguina? *Hincks*, p. 3.
sica, *Norman*	= Æ. recta, *Hincks*, p. 6.
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[1] All the page references are to Mr. Hincks' *British Marine Polyzoa.*

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„ (pt.), *D'Orb.* . . .	= Schizoporella, p. 237.
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calomorpha, *Reuss* . . .	= Cribril. radiata, *Moll.*, p. 185.
cantharıformis, *Busk* . .	= Lepralia, *id.*, p. 299.
capitata, *Reuss* . . .	= Chorizopora Brongniartii, p. 224.
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fulgarens, *Manz.* . . .	= Mucronella coccinea, p. 372.
glabra, *Reuss* . . .	= Microporella ciliata, p. 206.
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hastata, *Hincks* . . .	= Schizoporella linearis, p. 247.
immersa, *Johnst.* . . .	= Mucronella Peachii, p. 360.
innominata, *Reuss* . . .	= Cribril. radiata, p. 185.
insignis, *Hass.* . . .	= Microporella ciliata, p. 206.
intermedia, *Reuss* . . .	= Schizoporella vulgaris, p. 245.
Jacotina, *Gray* . . .	= Chorizopora Brongniartii, p. 224.
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lunata, *Macgil.* . . .	= Microporella ciliata, p. 206.
mamillata, *S. Wood* . .	= Mucronella coccinea, p. 372.
multiradrata, *Reuss* . .	= Cribril. radiata, *Moll.*, p. 185.
macrostoma, *Norman* . .	= Mucronella, *id.*
ochracea, *Hincks* . . .	= Schizoporella auriculata, p. 260.
otophora, *Reuss* . . .	= Schizop. vulgaris, p. 244.
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plaigopora, *Busk* . . .	= Microporella violacea, p. 216.
pretiosa, *Reuss* . . .	= Cribrilina radiata, p. 185.
pteropora, *Reuss* . . .	= Mucronella coccinea, p. 372.
pyriformis, *Busk* . . .	= Microporella impressa, p. 214.
quadricornuta, *Dawson* . .	= Mucronella coccinea, p. 372.
raricosta, *Reuss* . . .	= Cribrilina radiata, p. 186.
scripta, *Reuss* . . .	= „ „ p. 185.
serrulata, *Reuss* . . .	= Mucronella variolosa, p. 366.
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Steindachneri, *Heller* . .	= Cribrilina Gattyce, p. 198.
tenella, *Reuss* . . .	= Schizop. linearis, p. 247.
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tetragona, *Reuss*	= Schizoporella unicornis, p. 238.
thyreophora, *Busk*	= Microporella Malusii, p. 211.
tridentata, *Couch*	= Mucronella coccinea, p. 372.
utriculus, *Manzoni*	= Microporella ciliata, p. 206.
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Loricula, *Cuvier*	= Gemellaria Savig. p. 17.
Loricaria, *Lamarck*	= " "
Marginaria, *Rœmer*	= Membranipora, p. 128.
Membranipora.	
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Peachii, *Couch*	= „ Lacroixii, p. 130.
reticulum, *Reuss*	= „ " "
sacculata, *Norman*	= „ trifolium, p. 167.
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solida, *Packard*	= „ trifolium, p. 167.
stellata, *Thompson*	= „ pilosa, p. 137.
vulnerata, *Busk*	= Setosella, *id.*, p. 181.
Menipia fruticosa, *Packard*	= Bugula Murrayana, p. 92.
Smitti, *Norman*	Allied to M. Jeffreysii, p. 43.
Millepora, *Linn.* (pt.)	= Retepora of authors, p. 388.
Millepora compressa, *Sowerby*	= Porella, *id.*, *Hincks*, p. 330.
tenialis, *Ell. & Sol.*	= Lepralia foliacea, p. 300.
Mollia, *Smitt* (pt.)	= Hippothoa.
tuberculata, *D'Orb.*	= Chorozopora Brongniartii, p. 224.
Brongniartii, *D'Orb.*	= " " "
Nellia Johnsonii, *Busk*	= Cellaria Johnsonii, p. 112.
Onchopora, *Busk*	= Porina, *D'Orb* & *Hincks*, p. 227.
Ornithopora, *D'Orb.*	= Bugula avicularis, *Linn.*, p. 173.
Ornithoporina, *D'Orb.*	= Bugula, *Oken*, p. 173.
Porella cervicornis, *Gray*	= Porella compressa, p. 331.
Porellina, *Smitt*	= Microporella, *Hincks*, p. 204.
Pyripora ramosa, *D'Orb.*	= Membranipora catenularia, p. 134.
Quadricellaria, *Sars*	= Porina, *D'Orb.*, p. 227.
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Reptelectrina pilosa, *D'Orb.*	= Membranipora, *id.*, p. 137.
dentata, *D'Orb.*	= " " "
Repteschareila, *D'Orb.*	= Cribrilina, p. 184.
Hermanni, *Gabb. & Horn.*	= Cribril. annulata, p. 193.
Repteschareilina, *D'Orb.* (pt.)	= Micropora (pt.), p. 173.
	= Steganoporella (pt.), p. 176.
rhomboidalis, *D'Orb.*	= Chorizopora Brongniartii, p. 224.
Reptcelleporaria, *D'Orb.*	= for incrusting *Celleporæ.*
Reptoflustra telacea, *D'Orb.*	= Membran. membranacea, p. 140.
Reptoporellina subvulgaris, *D'Orb.*	= Microporella ciliata, p. 206.
Reptoporina, *D'Orb.* (pt.)	= Microporella, *Hincks.*
„ „ (pt.)	= Schizoporella, *Hincks.*
„ hexagona, *D'Orb.*	= Microporella Malusii, p. 211.

Retepora cellulosa, *Johnst. & Sars* (pt.)	= Ret. Beaniaria, *King*, p. 391.
Salicornia, *Schweigger*	= Cellaria, p. 104.
Salicornaria, *Cuvier*	,, ,,
Salpingia Hassallii, *Copin*	= Ætea truncata, p. 8.
Scrupocellaria Delilii, *Busk*	= Scrup. scabra, p. 48.
Selbia, *Gray*	= Caberea, p. 57.
Semiflustra (sp.) *D'Orb.*	= Flustra, *Linn.*, p. 114.
Tata rugosa (pt.) *Van Ben.*	= Memb. lineata, p. 144.
Terebripora (pt.) *D'Orb.*	= ? Hippothoa, p. 286.
Tessaradoma (sp.) *Norman*	= Porina, *Hincks*, p. 227.
Tricellaria ternata, *Flem.*	= Mempia *id.*, p. 36.
Unicellaria, *D. Blainv.* (pt.)	= Eucratea, *Lamx.*
Vinculariadæ, *Busk*	= Cellariidæ, *Hincks.*

Synonyms, Busk's 'Challenger' Report.

Names in right-hand column adopted in present and in the 'Challenger' Report.

Achamarchis	
neritina, *Lamx.*	= Bugula nentina, *Lamx.*
Acropora	
coronata, *Reuss*	= ? Eschara elegantula, *D'Orb.*
Alysidium, *Busk* (part)	= Catenaria.
Amastigia	
Amphiblestrum, *Gray*	= See Membraniporidæ, *Busk.*
Anarthropora, *Smitt*	
borealis	= Tessaradoma *id.*
Anguinaria anguina, *Flem.*	= Ætea *id.*, *Busk*, C. R.
spalulata, *Lamk.*	= Ætea anguina, C. R.
Annulipora, *Gray*	= Membranipora.
Antipathis humilis, *Agassiz & Pourtalès*	= Bifaxaria lævis, *Busk.*
Aspidostoma crassum, *Hincks*	= Aspidostoma giganteum, *Busk.*
Avicella, *Van Ben.*	= Bugula, *Oken.*
Berenicea, *Johnst.* (pars)	= Smittia, *Hincks.*
Biflustra, *D'Orb.*	Still employed by *Busk.*
crassa, *Haswell*	= Steganoporella magnilabris, *Busk.*
Lacroixii, *Smitt*	= Membranipora crassimarginata, *Hincks* = *var.* β, incrustans, *Busk.*
Bugula umbella, *Smitt*	= Kinetoskias aborescens, *Dan.*
Smittia, *Sars*	= Kinetoskias Smittia, *Kor. & Dan.*
Bugulina, *Gray*	= Bugula, *Oken.*
Caberea boryi, *Aud.*	= Caberea Lyalli, *Busk.*
Patagonica, *Busk*	= ,, Darwinii, *Busk.*
Zelanica, *Busk*	= ,, ,,
Carbasea	Still employed by *Busk.*
bombycina, *Busk*	= Onchoporella *id.*, *Busk.*
Catenaria chelata, *D'Orb.*	= Eucratea *id.*

Catenicella bicuspis, *Gray*	= Catenicella hastata, *Busk.*
Savignyi, *Blainv.*	= „ elegans, *Busk.*
(ventricosa, *var.* maculata)	= „ ventricosa, *Busk.*
Cellaria anguina, *Solander*	= Ætea anguina.
attenuata, *D'Orb.*	= Salicornaria gracilis, *Busk.*
barbata, *D'Orb.*	= Tubucellaria hirsuta, *Busk.*
catenularia, *Lamk.*	= Catenicella ventricosa, *Busk.*
cereoides (pars), *Lamk.*	= Tubucellaria opuntioides, *Busk.*
chelata	= Eucratea *id.*
cirrata, *Ell. & Sol.*	= Menipia *id.*, *Lamk.*
coronata, *Reuss*	= Eschara elegantula.
crispa, *Gmelin*	= Menipia cirrata, *Lamx.*
flabellum, *Ell. & Sol.*	= Menipia *id.*, *Busk.*
filifera, *Lamk.*	= Canda arachnoides, *Lamk.*
fistulosa, *Macgil.*	= Salicornaria clavata, *Busk.*
„ *var.* australis, *Hincks*	„ „ „
gracilis, *Macgil.*	„ *id.*, *Busk.*
hirsuta, *Lamk.*	= Tubucellaria *id.*, *Busk.*
Malvinensis, *Waters*	= Salicornaria *id.*, *Busk.*
neritina, *Sol.*	= Bugula *id.*, *Busk.*
salicornoides, *Savig.*	= Salicornaria gracilis, *Busk.*
tenuirostris, *Macgil.*	„ bicornis, *Busk.*
tenuirostris, *Smitt*	„ *id.*, *Busk.*
Cellepora avicularis, *Smitt*	= Cellepora conica, *Busk.*
bispinata, *Busk*	„ albirostris, *Smitt.*
ciliata, *Linn.*	= Microporella *id.*, *Busk.*
Costazzi, *var.* tubulosa, *Hincks*	= Cellepora tubulosa, *Busk.*
malussi, *Aud.*	= Microporella *id.*
mamillata, *Busk*	= Cellepora *id.*, *var.* Atlantica, *Busk.*
verruculata, *Smitt*	= Escharoides *id.*, *Busk.*
Cellularia anguina, *Pallas & Ellis*	= Ætea *id.*
chelata, *Ell. & Sol.*	= Eucratea *id.*
neritina, *Pallas*	= Bugula *id.*
opuntioides, *Pallas*	= Tubucellaria *id.*
ornata, *Busk*	= Menipia flabellata, *Busk.*
Chaunosia hirtissima, *Busk*	= Diachoris *id.*, *Heller.*
Cothurnicella dædala, *Wyv. Thoms.*	= Chlidonia cordieri.
Cribrilina figularis, *var.*	= C. philomela, *Busk.* *Var.* adnata, *Busk.*
speciosa, *Hincks*	= C. philomela, *Busk.*
Crisia chelata, *Johnst.*, *Hassall*	= Eucratea *id.*
ciliata, *Aud.*	= Scrupocellaria ciliata, *Busk.*
„ „	„ diadema, *Busk.*
ornithorhyncus, *W. Thoms.*	„ *id.*
pilosa, *Savig.*	„ „
Cupularia denticulata, *Conrad*	= Cupularia Owenii, *Busk.*
Diachoris Buskei, *Heller*	= D. Magellanica, *Busk.*
Dictyopora, *Macgil.*	= Adeona, *Busk.*
Diplopora, *Macgil.*	Genus of Microporidæ.
Discopora albirostris, *Smitt*	= Cellepora *id.*
coriacea, *Lamk.*	= Micropora *id.*, 'Chal. Rep.'
Epicaulidium pulchrum, *Hincks*	= Pasythea eburnea, *Lamk.*

Eschara Buskii, *Ten. Wood* . .	= Eschara gracilis, *Lamk.*
ciliata, *var.* β. *Pal.* . . .	= Microporella *id.*
contorta, *Busk* . . .	= Mucronella *id. Busk.*
cosciniphora, *Reuss* . . .	= Adeonella distoma, *Busk.*
gigantea, *Busk* . . .	= E. giganteum, *Busk.*
hexagoniles, *Haswell* . .	= Adeonella platelea, *Busk.*
lichenoides, *Milne-Edw.* . .	= ? Adeonella intricaria, *Busk.*
platalea, *Busk* . . .	= Adeonella *id.*, *Busk.*
radiata, *Moll.*	= Cribrilina *id.*, *Busk*, *Smitt.*
saccata, *Busk*	= Eschara elegantula, *D'Orb.*
Escharella bisinuata, *Smitt* . .	= Mucronella *id.*
Escharina Bougainvillei, *D'Orb.* .	= Chorizopora hyalina, *var.*
cornuta, *D'Orb.* . . .	= Microporella Malussi.
elegans, *D'Orb.* . . .	= Schizoporella *id.*, *Busk.*
elegans, (*pars*) *Milne-Edw.* .	= Microporella ciliata.
Escharipora, *Smitt* . . .	= Cribrilina.
Eucratea Contei, *Aud.* . . .	= Catenicella elegans, *Busk.*
Cordieri, *Aud.*	= Chlidonia *id.*
Lafontii, *Aud.*	(Type) Catenaria, 'Chal.' Rep.
loricata	= Eucratea chelata.
Falcaria anguina	= Ætea *id.*, 'Chal.' Rep.
Farcimia, *Fleming*	= Salicornaria, *Busk.*
Farciminaria aculeata, *Busk* . .	Near F. Atlantica, *Busk.*
Flustra bombycina, *Linn.* . .	= Onchoporella *id.*, *Busk.*
Brongniartii, *Aud.* . . .	= Chorizopora *id.*
carbasea, *var.* β, *Lamk.* . .	= Carbasea dissimilis, *Busk.*
Cecilli, *Aud.*	= Schizoporella *id.*, *Busk.*
coriacea, *Esper.*	= Micropora *id.*
denticulata, *var.* inermis, *Busk*	= Flustra denticulata, 'Chal.' Rep.
Genisii, *Aud.*	= Microporella ciliata.
margaritifera, *Quoy & Gaym.* .	= Lepralia *id.*, 'Chal.' Rep.
Savartii, *Aud.*	= Biflustra *id.*
marginata, *Kraus* . . .	= Flustramorpha *id.*, *Busk.*
Genellipora eburnea, *Smitt* . .	= Pasythea *id.*, 'Chal.' Rep.
lata, *Smitt*	= Lepralia (?) 'Chal.' Rep., p. 146
Halophila, *Busk*	= Bugula, *Oken.*
Hemeschara, *Busk*	= Lepralia, (pars), and Porella, *Gray*, (pt.)
Herentia, *Gray* (pt.) . . .	= Microporella, *Hincks.*
biforis, *Gray*	,, Malussi, *Busk.*
Hippothoa catenularia . . .	= Genus Pyripora, *Busk.*
Kinetoskias aborescens, *Don.* . .	— Bugula umbella, *Smitt.*
Smittii, *Kor. & Don.* . .	= K. cyathus, *W. Thoms.*
Lepralia ansata	= Schizoporella tenuis, *Busk.*
assimilis, *Johnst.* . . .	= Chorizopora Brongniartii.
bella, *Busk*	Near Smittia stigmatophora, *Busk.*
biforis, *Johnst.* . . .	= Microporella Malussi.
Brongniartii, *Busk* . . .	= Chorizopora *id.*
capitata, *Reuss* . . .	,, Brongniartii.
Cecilli, *Busk*	= Schizoporella *id.*, *Busk.*
cheilostoma, *Manzoni* . .	= Smittia stigmatophora, *Busk.*
ciliata, *Johnst.* &c. . . .	= Microporella *id.*
circinata, *Macgil.* . . .	= Schizoporella *id.*

Lepralia.	
collaris	= Phylactella *id.*, *Hincks.*
diadema, *Macgil.*	= ? Onchoporella *id.*, *Busk.*
distoma, *Busk.*	= Adeonella *id.*, *Busk.*
hyalina, *var.* Bougainville, *Busk*	= Chorizopora hyalina.
insignis, *Hassall*	= Microporella ciliata, *Busk.*
labiosa, *Busk*	= Phylactella *id.*, *Hincks.*
labrosa, *Busk*	= Phylactella *id.*, *Hincks.*
larvalis, *Busk*	= Cribrilina monceros, *Busk.*
lunata, *Macgil.*	= Microporella ciliata.
magnevilla, *Busk*	= Mucronella (Phylactella) canelifera, *Busk.*
Malussi, *Busk*, *Heller*, *Manz.*	= Microporella Malussi, *Busk* & *Hincks.*
Marionensis, *Busk*	= Smittia *id.*, *Busk.*
minuta, *Norman*	= To or near Lepralia marsupium, *Macgil.* & *Busk.*
monoceros, *Busk*	= Cribrilina *id.*, *Busk.*
multispinata, *Busk*	= Mucronella ventricosa, *var.* multispinata, *Busk.*
Palasiana	= Lepralia, *Busk*, but limited.
personata, *Busk*	= Microporella *id.*, *Busk.*
pertusa	= Limited to Lepralia, but having character similar to Phylactella, *Hincks*, 'Chal.' Rep. p. 146.
radiata, *Busk*	= Cribrilina *id.*
squamoidea, *Reuss*	= Schizoporella elegans, *Busk.*
tenuis, *Hassall*	= Chorizopora Brongniartii.
unicornis	= Schizoporella.
utriculus, *Manzoni*	= Microporella ciliata.
Woodiania, *Busk*	Near Lepralia incisa, *Busk.*
Lirioza, *Lamk.*	= Pasythea, *Lamk.*
Lunulites, *Lamx.*	= Lunularia, *Busk.*
capulis, *Busk*	= Lunularia *id.*, *Busk.*
Owenii, *Gray*	= Cupularia *id.*, *Busk.*
alveolatus, *G. Wood*	= Cupularia Owenii, *Busk.*
Malakosaria pholaramphos, *Goldst.*	= Onchopora Sinclairii, *Busk.*
Marginaria, *Rom.* (pt.)	= Membranipora, *Blainv.*
Mastigophora, *Hincks*	= Flustramorpha (pars), *Gray.*
Meliceritina, *Ehrenb.*	= Melicerta, *Milne-Edw.*
Membranipora catenulara	= Pyripora *id.*, *Busk.*
ciliata, *Macgil.*	= M. spinosa, *D'Orb.*
cervicornis, *Busk*	= Amphliblestrum *id.*, *Busk.*
coriacea, *Busk*	= Micropora *id.*, 'Chal.' Rep.
corrugata, *Blainv.*	= Biflustra Savartii.
Flemingii	Type of Amphiblestrum, *Busk*
magnilabris, *Busk*	= Steganoporella *id.*
Savartii, *D'Orb.*	= Biflustra *id.*
umbonata, *Busk*	= Amphiblestrum *id.*
Menipea, feugensis, *Busk*	= M. aculeata, *D'Orb.*
Mollia Brongniartii, *D'Orb.*	= Chorizopora *id.*
hyalina, *var.* divaricata, *Sm.*	= Hippothoa.
Myriozoidæ, *Smitt*, *Hincks*	Escharidæ and Celleporidæ.

1885.

Myrizoum Australiensis, *Haswell*	= Haswellia *id. Busk.*
Naresia cyathus, *W. Thoms.*	= Kinetoskias *id.*
Onchopora borealis, *Busk.*	= Tessaradome boreale, *Busk.*
hirsuta, *Busk*	= Tubucellaria *id.*, *Busk.*
Phylactella collaris, *Hincks*	= Lepralia *id.*, *Busk.*
labrosa, *Hincks*	= Lepralia *id.*, *Busk.*
Porella concinna, *var.* gracilis, *Hks.*	= Smittia graciosa, *Busk.*
marsupium, *Hincks*	= Lepralia marsupium, *Macgil.* & *Busk.*
minuta, *Norman*	= ? Lepralia marsupium, *Macgil.* & *Busk.*
Porellina ciliata, *Smitt*	= ? Flustramorpha hastigera (pars) and Microporella ciliata.
coscinophora, *D'Orb.*	= Adeonella distoma, *Busk.*
Porina borealis, *Hincks*	= Tessaradoma boreale, *Busk.*
ciliata, *Smitt*	= Microporella *id.*
Malusii, *Smitt*	= Microporella *id.*
Pustulopora gracilis, *Sars*	= Tessaradoma boreale
Pyripora, *D'Orb.*	= 5th Genus of Membraniporidæ, *Busk.*
Quadricellaria gracilis, *Sars*	= Tessaradoma boreale, *Busk.*
Reptelectrina, *D'Orb.*	= Electra, *Lamx.*
Repteschareila inequalis, *D'Orb.*	= Cribrilina philomela, *Busk.*
Repteschareilina, *D'Orb.*	= Micropora, *Gray.*
Reptoporina, *D'Orb.* (pt.)	= Microporella & pt. Schizoporella.
Malusii, *D'Orb.*	= Microporella *id.*
Retepora carinata, *Macgil.*	= R. Victoriense, *Busk.*
cellulos (pars)	= R. Imperati, *Busk.*
,, *var.* marsupiata, *Smitt*	= R. Atlantica, *Busk.*
cornea, *Busk.*	= Carbusea cribriformis, *Busk.*
elongata, *D'Orb.*, *Smitt*, *var.*	= R. Imperati, *Busk.*
monilifera, *Macgil.*	= R. hirsuta, *Busk.*
Salicornaria punctata, *Busk.*	= Salicornaria gracilis, *Busk.*
tenuirostris, *var.* bicornis, *Busk*	= ,, bicornis, *Busk.*
Schizoporella marsupium, *S. O. Ridley*	= Lepralia marsupium, *Macgil.* & *Busk.*
Scruparia chelata, *Oken*	= Eucratea *id.*
Scrupocellaria clypeata, *Hassall*	= S. ornithorhyncus, *W. Thomp.*
diadema, *Busk*	= S. ciliata, *Aud.*
Selbia Zelanica, *Gray*	= Caberea rostrata, *Busk.*
Semiflustra bombycina, *D'Orb.*	= Onchoporella *id.*
Sertularia anguina, *Linn.*	= Ætea *id.*
chelata, *Linn.*	= Eucratea *id.*
cirrata, *Gmelin*	= Menipea *id. Lamx.*
crispa, *Gmelin*	= ,, cerrata, *Lamx.*
mollis, *Della Chaig.*	= Ætea anguina.
neritina, *Linn.*	= Bugula *id.*
opuntioides, *Gmelin*	= Tubucellaria *id.*
Smittia affinis, *Hincks*	= near S. transversa, *Busk.*
bella, *Busk*	= Lepralia *id.*, near S. stigmatophora.
cheilostoma, *Manzoni*	= near S. stigmatophora.

Smittia.	
Landsborovii	= near S. Jacobensis, *Busk.*
marmorea, *Hincks* . . .	= S. oratavensis, *Busk.*
Steganoporella Neo-Zelanica, *Waters*	= S. magnilabris, *Busk.*
elegans, *Smitt*	= " "
Stiparia glabra, *Hincks* . . .	= Bicellaria glabra, *Busk.*
Ternicellaria aculeata, *D'Orb.* .	= Menipia *id.*
Tessaradoma boreale, *Smitt* . .	= T. boreale, *Busk.*
gracilis, *Norman* . . .	= " "
Tricellaria aculeata, *D'Orb.* . .	= Menipea *id.*
Tubucellaria barbata, *D'Orb.* . .	= T. hirsuta, *Busk.*
cereoides, *Lamx.* . . .	= T. opuntioides, *Busk.*
Vincularia Novæ-Hollandiæ, *Haswell*	= V. Gothica, *D'Orb.*
steganoporoides, *Macgil.* .	= " "
Unicellaria chelata, *Blainv.* . .	= Eucratea *id.*

List of Synonyms from Rev. Thomas Hincks' 'Brit. Mar. Polyzoa.' —Cyclostomata.

Names in right-hand column adopted by Mr. Hincks.

Actinopora regularis, *D'Orb.* .	= Lichenopora *id.*
Alecto parasita, *Heller* . .	= Stomatopora granulata.
" granulata, *Johnst.* . .	= " Johnsoni, *Heller.*
= repens, *Manzoni* . .	= " dilatans.
= retiformis, *Hincks* . .	= " incrassata.
Aulopora (pt.), *Goldfuss* . .	= Stomatopora.
Auloporina (pt.), *Ehrenb.* . .	= Cyclostomata, *Busk.*
Berenicea (pt.), *Lamx.* . .	= Diastopora.
Caveidæ (pt.), *D'Orb.* . . .	= Lichenoporidæ.
Ceriopora, *Hagenow* . . .	= Tubulipora.
Coronpora, *Gray*	= Domopora.
Corymbopora fungiformis, *Smitt* .	= " stellata.
Crisia aculeata, *Hassall* . . .	= Crisia eburnea.
" arctica, *Sars* . . .	= " denticulata.
" attenuata, *Heller* . . .	= " "
" geniculata, *M.-Ed.* . .	= " cornuta.
" Haueri, *Reuss* . . .	= " eburnea.
" luxata, *Flem.* . . .	= " denticulata.
" producta, *Smitt* . . .	= " eburnea.
" setacea, *Couch* . . .	= " cornuta.
Crisidia cornuta	= " "
Crisina, *D'Orb.*, *Smitt* . . .	= Idmonea.
Defrancia (pt.), *Reuss*, *Hagen.*, *Sars*, *Manz.*	= Domopora.
Diastopora flabellum, *Reuss* . .	= Diastopora suborbicularis.
" hyalina (pt.), *Smitt* .	= " sarniensis.
" plumila, *Reuss* . .	= Tubulipora flabellaris.
" repens (pt.), *Smitt* .	= Stomatopora dilatans.
" simplex, *Busk* . .	= Diastopora suborbicularis.
Discocavea aculeata, *D'Orb.* . .	= Lichenopora hispida.

Discocavea verrucaria, *D'Orb.* .	= Lichenopora radiata.
Discoporella flosculus, *Hincks* .	= ,, ,,
Discotubigera, *D'Orb.* . . .	= ,,
Falcaria (pt.), *Oken* . . .	= Crisia.
Filissparsa incrassata, *D'Orb.* .	= Stomatopora *id.*
Heteroporella, *Hincks* . . .	= Lichenopora.
Hornera borealis, *Busk* . . .	= Hornera lichenoides.
,, frondiculata, *Sars* . .	= ,, ,,
Idmonea angustata, *D'Orb.* . .	= Idmonea atlantica.
,, coronopis, *Def.* . .	= ,, ,,
,, dilatata, *M.-Ed.* . .	= ,, serpens.
,, radians, *Van Ben.* . .	= ,, atlantica.
,, transversa, *M.-Ed.* . .	= ,, serpens
Millepora liliacea, *Pall.* . .	= ,, ,,
Obelia tubulifera, *Lamx.* . .	= ,, ,,
Patinella verrucaria, *Gray* . .	= Diastopora patina.
Proboscina latifolia, *D'Orb.* . .	= Tubulipora fimbria.
,, ramosa, *D'Orb.* . .	= Stomatopora expansa.
Pustulopora gracilis, *Sars* . .	= Porina borealis, *Busk.*
,, proboscidea, *Johnst.* .	= Palmicellaria elegans.
,, orchadensis, *Busk* .	= Hornera violacea.
Radiopora (pt.), *D'Orb.* . .	= Lichenopora.
Reptotubigera confluens, *D'Orb.* .	= Idmonea serpens.
Semimulticava (pt.), *D'Orb.* . .	= Domopora.
Sophodictyum, *Lonsd.* . . .	= Hornera.
Stellipora, *Hagenow* . . .	= Domopora.
Tubulipora foraminulata, *Reuss* .	= Idmonea serpens.
,, penicillata, *Johnst.* .	= Stomatopora fungia.
,, phalangea, *Couch* .	= Tubulipora flabellaris.
,, repens, *S. Wood* . .	= Stomatopora major.
,, serpens, *Busk* . .	= Tubulipora lobulata.
,, verrucaria, *M.-Edw.* .	= ,, flabellaris.
Tubuliporina, *M.-Edw., Johnst.* .	= Cyclostomata, *Busk.*
Unicavea, *D'Orb.*	= Lichenopora.

GEOGRAPHICAL AND BATHYMETRICAL DISTRIBUTION OF MARINE POLYZOA.

Part I.

The Distribution of Cheilostomatous and Cyclostomatous Polyzoa in the Arctic and Atlantic Seas.

In the following lists I have compiled from various sources the range and distribution of species around a given centre, if I may be allowed to call it such. For this purpose I have taken the whole of the species and varieties described by Mr. Hincks in his 'British Marine Polyzoa,' and have numbered them, 1 to 256, so that by this means an easy reference may be made to any particular form. The localities are indicated by

means of columns and letters, of which the following is a full explanation :—

Col. 1. Shetland, *a* ; Orkney Isles, *b* ; Unst and Hebrides, *c*.
2. East Coast : Scotland, *d* ; Northumberland, *e* ; Durham and Yorkshire, *f*.
3. South-east Coast : Hastings, *h* ; Brighton, *i*.
4. Devon, *j* ; Cornwall, *k* ; West Coast of Ireland, *m''*.
5. West Coast of England, *l* ; EastCoast of Ireland, *m* ; Antrim, *m** ; Isle of Man, *m'*.
6. Guernsey, *n* ; Jersey, *o*. (When every column is filled by an (*) a wide distribution is indicated.)
7. Fossil range : Brit. Glacial, 1 ; Crag, 2 ; Pliocene, 3* ; Miocene, *Reuss*, 3 ; Eocene, 4.

Explanation of the arrangement of the figures in the left-hand column.

This British list is completely arranged in accordance with the classification adopted by Mr. Hincks. It will be seen that the generic and specific arrangement is different from that adopted in the first part of the Report, and to keep up a complete uniformity the following explanation was necessary :—

I. The family names in the British list are those used by Mr. Hincks.
II. So also are the generic ; but against every generic name a number has been placed, and this will be found to correspond with the number and placement of the genus in the classification of Mr. Busk and also the classification adopted by me in the present Report.
III. For obvious reasons I have only numbered in consecutive order the British list. The CYCLOSTOMATA is likewise numbered consecutively, but the columns are differently arranged.

In the other lists the genera are numbered similarly to the British list on the left-hand side, but in the first right-hand column the space is reserved. If the species named is found in any British locality, the number in the British list is given ; if not, the space is left bare. By this simple method, and without disturbing the text and arrangement of different authors, a uniformity of nomenclature throughout the whole of the Report is secured. The blank spaces will sufficiently indicate the species peculiar to any special area.

The same plan is adopted in the list furnished from Mr. Busk's 'Challenger' Report of the bathymetrical distribution of species in the seven regions given by the author. In the last column of this list the geographical distribution is indicated by the use of the following letters, as given by Mr. Busk in the Report, pp. iii to xv of preface :—

A. North Atlantic region ; *B.* South Atlantic region ; *C.* South Indian or Kerguelen region ; *D.* Australian region ; *E.* Philippine or Japanese region ; *F.* North Pacific region ; *G.* South Pacific region.

Complete List of British Marine Polyzoa: Hincks, Norman, Barlee, and Alder. Described by the Rev. Thos. Hincks, 'British Marine Polyzoa,' 1880.

		1	2	3	4	5	6	7
	SUB-ORDER I. **CHEILOSTOMATA**							
	Fam. **Æteidæ**							
1	Ætea, *Lamx.*							
1	anguina, *Linn.*	*a* =	*f*	*h, i*	*j, k*	*m*	*n*	
2	recta, *Hincks*	*a*			*j*	*mm'*	*n*	
3	truncata, *Landsb.*				*j*	*m'*	*n*	
	Fam. **Eucrateidæ**							
2	Eucratea, *Lamx.*							
4	chelata, *Linn.*	*	*	*	*	*	*	
5	α repens					*m'*		
6	β gracilis				*j*			
22	Gemellaria, *Savigny*							
7	loricata, *Linn.*	*	*	*	*	*	*	
25	Scruparia, *Hincks*							
8	clavata, *Hincks*		*f*			*m''*		
27	Huxleya, *Dyster*							
9	fragilis, *Dyster*[1]							
26	Brettia, *Dyster*							
10	pellucida, *Dyster*[1]							
11	tubæformis, *Hincks*	*c*		*g*				
	Fam. **Cellulariidæ**, *Busk*							
9	Cellularia, *Pallas*							
12	Peachii, *Busk*	*a*	*d, f*					
10	Menipea, *Lamx.*							
13	ternata	*a*	*d, f*					
14	Jeffreysii, *Norman*	*a*						
12	Scrupocellaria, *Van Ben.*							
15	scruposa, *Linn.*	*	*	*	*	*	*	1, 2, 3
16	elliptica, *Reuss*	*a, c*						3
17	scabra, *Van Ben.*		2[2]					
18	scrupea, *Busk*		2 =	*			*n*	
19	reptans, *Linn.*	*	*	*	*	*	*	1
15	Caberea, *Lamx.*							
20	Ellisi, *Flem.*	*a, b*				*m* *		
21	Boryi, *Aud.*			*g* =			*n, o*	
	Fam. **Bicellariidæ**							
16	Bicellaria, *Blainv.*							
22	ciliata, *Linn.*	*a*	*d, e, f*	*g*	*			
23	Alderi, *Busk*	*a, a'*						
17	Bugula, *Oken*							
24	avicularia, *Linn.*	*a, c*	*d, e*	*h*	*j, k*			
25	turbinata, *Alder*		*e, f*		*	*l, m'*	*n*	
26	flabellata, *J. V. Thomp.*	*	*	*	*	*	*	
27	calathus, *Norman*				*j*			
28	plumosa, *Pallas*		*e*	*j, k ?*				
29?	gracilis, *Busk*							
30?	uncinata, *Hincks*							
31	purpurotincta, *Nor.*	*a*	*d–f*					

[1] Tenby.

[2] * = Two or more localities.

Complete List of British Marine Polyzoa—continued.

		1	2	3	4	5	6	7
	Fam. **Bicellariidæ**—*cont.*							
	Bugula.							
32	Murrayana, *Johnst.*	*b*	*d–f*			*m*		
33?	α fruticosa, *Packard*							
20	Beania, *Johnst.*							
34	mirabilis, *Johnst.*		*d=*	*g=*	?	*m*	*n*	
	Fam. **Notamiidæ**							
21	Notamia. *Flem.*							
35	bursaria, *Linn.*			*g, h, i*	*j*			
	Fam. **Cellariidæ**							
47	Cellaria, *Lamx.*							
36	fistulosa, *Linn.*	*	*	*	*	*	*	
37	sinuosa, *Hassall*	*a*	*e*		*j, k*	*m*		2
38	Johnsoni, *Busk*	*a*						
	Fam. **Flustridæ**							
29	Flustra, *Linn.*							
39	foliacea, *Linn.*	*	*	*	*	*	*	
40	papyracea, *Ell.* and *Sol.*			*h, i*	*k=j*	*m*		
41	securifrons, *Pallas*	*a*	*d, e, f*			*m*		
42	α papyracea, *Dalyell*		*d, e*					
43	Barleei, *Busk*	*a*						
44	carbasea, *Ell.* and *Sol.*	*a*	*d, e, f*			*m*		
	Fam. **Membraniporidæ**							
32	Membranipora, *Blainv.*							
45	Lacroixii, *Aud.*			*h*	*k, j*			1, 2, 3
46	monostachys, *Busk*			*g, h*				2, 3
47	*Var.* α (Yarmouth)							
48	catenularia, *Jameson*	*	*	*	*	*	*	1, 2, 3
49	pilosa, *Linn.*	*	*	*	*	*	*	
50	α dentata, *Hincks*							
51	β laxa, *Sars* and *Smitt*							
52	γ „ *Pallas*							
53	membranacea, *Linn.*	*	*	*	*	*	*	1, 2
54	hexagona, *Busk*				*j*	*m′*		
55	lineata, *Linn.*	*	*	*	*	*	*	3* 3
56	craticula, *Alder*	*a*	*d, e*		*k*	*m′*		1
57	spinifera, *Johnst.*	*a*	*d, e*		*j, k*	*m′*		
58	flustroides, *Hincks*				*j, k*	*m**	*n*	
59	discreta, *Hincks*				*j*		*n*	
60	curvirostris, *Hincks*				*			
61	unicornis, *Flem.*		*d, e*					1
62	Dumerili, *Aud.*	*a, c*		*h*	*j, k*	*m*		1
63	solidula, *Ald.* and *Hincks*			*h*	*m*	*m**	*n*	
64	aurita, *Hincks*		*e*		*j, k*	*m**		
*65	imbellis, *Hincks*	*a*			*j=*	*m**		
66	Flemingii, *Busk*	*	*	*	*	*	*	1
67	cornigera, *Busk*	*a=*						
68	Rosselii, *Aud.*	*a, b*	*d*			*m*	*n*	
69	trifolium, *S. Wood*	*a*						1
70	α quadrata		*d=*					
71	minax, *Busk*	*a*						
72	nodulosa, *Hincks*				*j*	*m**		
37?	Megapora, *Hincks*							
73	ringens, *Busk*	*a*						

Complete List of British Marine Polyzoa—continued.

		1	2	3	4	5	6	7
	Fam. **Microporidæ**							
38	Micropora, *Gray*							
74	coriacea, *Esper.*	*a*	*d*	*h*	*k*	*m**	*n*	
75 ?	complanata, *Norm.*							3*
40	Steganoporella, *Smitt*							
76	Smittii (see *Hincks*, p. 178)				*k*			2
43	Setosella, *Hincks*							
77	vulnerata, *Busk*	*a*						
	Fam. **Cribrilinidæ**							
60	Cribrilina, *Gray*							
78	radiata, *Moll.*	*a* =	*	*	*	*	*	
79	*Var.* α					*m**		
80	„ β							
81	„ γ tenuirostris							
82	punctata, *Hass.*	*	*	*	*	*	*	2, 3*
83	*Var.* α							
84	annulata, *Fabric.*	*a*			*k*	*m**		1
85	figularis, *Johnst.*			*h*	*k*	*m**	*n*	2
86	Gattyæ, *Busk*			*h*			*n*, *o*	
87	*Var.* α			*h*				
61	Membraniporella, *Hincks*							
88	nitida, *Johnst.*	*	*	*	*	*	*	
89	melolontha, *Busk*			*				
	Fam. **Microporellidæ**							
63	Microporella, *Hincks*							
90	ciliata, *Pallas*	*	*	*	*	*	*	2, 3, 3*
91	*Var.* α personata, *Busk*			*h*	*j*, *k*	*m′*		
92	Malusii, *Aud.*	*	*	*	*	*	*	2, 3*
93 ?	α thyreophora (*Austr.*)							
94	β vitrea							
95	impressa, *Aud.*	*a*	*d*			*h*		
96	α bimucronata, *Moll.* = *Var.* cornuta, *Busk*						*n*	
97	β glabra							
98	γ pyriformis, *Busk*							2
99	violacea, *Johnst.*				*k*	*m′*		1, 2, 3, 4
100	*Var.* α			*h*			*n*	
101	„ β plagiopora				*k*			2
	Diporula, *Hincks*							
102	verrucosa, *Peach*				*k*			3*
66	Chorizopora, *Hincks*							
103	Brongniartii, *Aud.*	*	*	*	*	*	*	2, 3, 3*a*
	Fam. **Poronidæ.**							
	Porina, *D'Orbigny*							
104	borealis, *Busk*	*a*						
105	tubulosa, *Norman*	*a*						1
	Anarthropora, *Smitt*							
106	monodon, *Busk.*	*a*						
51 ?	Lagenipora, *Hincks*							
107	socialis, *Hincks*			*h*				
	Celleporella [1]							

[1] See note and Nos. 214, 215.

Complete List of British Marine Polyzoa—continued.

		1	2	3	4	5	6	7
	Fam. **Myriozoidæ**, *Smitt.*							
72?	Schizoporella, *Hincks* . .							
108	unicornis, *Johnston* . .		*d, e*				*n*	2, 3
109	*Var.* ansata, *Reuss* . .	*a*		*h*	*k*			1,2,33*
110	spinifera, *Johnston* . .	*	*	*	*	*		
111	Alderi, *Busk* . . .	*a*						
112	vulgaris, *Moll* . . .			*h*	*j* ?	*m**		2, 3, 3*
113	simplex, *Johnston* . .	*c*	=	*h*	*j* =	*m**	*n*	1
114	linearis, *Hassall* . . .	*	*	*	*	*	*	
115	α hastata, *Hincks* . .			*	*j*		*n*	
116	β mamillata . . .							
117?	γ nitida							
118	δ crucifera, *Nor.* . .	*a'*						
119	sanguinea, *Norman* . .				*k*		*n*	
120	cristata, *Hincks* . . .			*h*				
121	biaperta, *Michelin* . .							2,3,3*
122	α eschariformis, *Wat.* .							
123	β divergens, *Smitt* . .			*h*			*n*	
124	armata, *Hincks* . . .				*			
125	auriculata, *Hassall* . .	*	*	*	*	*	*	3*
126	α ochracea . . .							3*
127	β cuspidata . . .							
128	umbonata, *Busk* . . .	*a*						
129	discoidea, *Busk* . . .	*a*		*h*		*m**	*n*	
130	sinuosa, *Busk* . . .							
131	α armata	*a*	*					
132	Cecilii, *Aud.*				*		*n, o*	
133	cruenta, *Nor.* . . .	*a* =						1
134	hyalina, *Linn.* . . .	*	*	*	*	*	*	1, 2
135?	α cornuta							
136	β incrassata . . .							
137?	γ tuberculata . . .							
138	venusta, *Norman* . . .						*n*	
	Mastigophora, *Hincks* . .							
139	Dutertrei, *Aud.* . . .					*m**		2, 3, 3*
140	*Var.* α				*k*	*m**		
141	„ β	*a*					*n*	
142	Hyndmanni, *Johnst.* . .	*				*		
54?	Schizotheca, *Hincks* . . .							
143	fissa, *Busk*				*			
144	divisa, *Norman* . . .					*m**	*n*	
3	Hippothoa, *Lamx.* . . .							
145	divaricata, *Lamx.* . .	*	*	*	*	*	*	1, 3*
146	α conferta . . .				?			
147	β carinata . . .					*m**		
148?	γ Patagonica, *Busk* . .							2
149	expansa, *Dawson* . . .	*a*						
150	flagellum, *Manzoni* . .	*	*	*	*	*	*	3*
	Fam. **Escharidæ** (pt.) *Smitt.*							
65	Lepralia, *Johnst.* (pt.) . .							
151	Pallasiana, *Moll.* . . .	*	*	*	*	*	*	2
152	cantharifomis, *Busk* . .	*a*						
153	foliacea, *Ellis* and *Sol.* .	*c*		*	*	*m'*		3*
154	α fascialis . . .			*j*				
155	β bidentata . . .							
156	pertusa, *Esper.* . . .	*	*	*	*	*m'*		1
157	adpressa, *Busk* . . .			*h*			*n*	3*
158	*Var.* α							
159	hippopus, *Smitt* . . .		*c*					

Complete List of British Marine Polyzoa—continued.

		1	2	3	4	5	6	7
	Fam. **Escharidæ**—*cont.*							
	Lepralia.							
160	edax, *Bush*					*j*	*n*	2, 3*
161	polita, *Norman*	*a*						
78?	Umbonula, *Hincks.*							
162	verrucosa, *Esper.*	*	*	*	* =	*	*	1
	Porella, *Gray*							
163	concinna, *Busk*	*	*	*	*	*	*	1
164?	α bella, *Dawson*							
165?	β gracilis							
166	minuta, *Norman*	* =		*h*		*m**	*	
167	struma, *Norman*	*						
168	compressa, *Sowerby*	*	*	*	*	*	*	
169	lævis, *Fleming*	*						
68	Escharoides, *Smitt*							
170	rosacea, *Busk*	*						
171	quincuncialis, *Nor.*	*						
69	Smittia, *Hincks*							
172	Landsborovii, *Johnst.*		*	*h*			*	
173	α crystallina, *Nor.*	*						1
174	β ? porifera, *Smitt*				*			
175	reticulata, *Macgil.*	*	*	*	*	*	*	
176	affinis, *Hincks*				*			
177	cheilostoma, *Manzoni*			*h*	*	*m''*	*	3*
178	marmorea, *Hincks*				*k*		*	
179	bella, *Busk*	*						
180	trispinosa, *Johnst.*	*	*	*	*	*	*	
181	α Jeffreysi, *Nor.*				?			
	Phylactella, *Hincks*							
182	labrosa, *Busk*	* =		*h*	* =			3*
183	collaris, *Norman*	*		*h*		*		
184	eximia, *Hincks*	*				*m**		
70	Mucronella, *Hincks* = Discopora, *Smitt*							
185	Peachii, *Johnst.*	*	*	*	*	*	*	1, 2, 3
186	α labiosa, *Busk*					*m*	*	
187	β octodentata	*						
188	ventricosa, *Hassell*	*	*	*	*	*	*	2, 3, 3*
189	variolosa, *Johnst.*	*	*	*	*	*	*	2, 3, 3*
190	laqueata, *Nor.*	*a c*				*m**		
191	abyssicola, *Nor.*	*a*						
192	microstoma, *Nor.*	*a*						
193	coccinea, *Abildg.*	*	*	*	*	*	*	2, 3, 3*
194	α mamillata					*m**		2
195	pavonella, *Alder*		*e, f*					
79?	Palmicellaria, *Alder*							
196	elegans, *Alder*	*a*						
197	Skenei, *Ell.* and *Sol.*		*d*					
198	α bicornis				*j* ?	*m*		2
199	β foliacea	*a*	*d, e*					
200	lorea, *Alder*	*a*						
201	? cribraria, *Johnst.*		?[1]					
53?	Rhyncopora, *Hincks*							
202	bispinosa, *Johnst.*	*a*	?[1]		*j, k*			
57	Retepora, *Imperato*							
203	Beaniana, *King*	*a, b*	*d, e*					
204	Couchii, *Hincks*				*k*		*	3*

[1] Berwick Bay.

Complete List of British Marine Polyzoa—continued.

		1	2	3	4	5	6	7
	Fam. **Celleporidæ**							
83	Cellepora, *Fabric.*							
205	pumicosa, *Linn.*	*	*	*	*	*	*	1
206	ramulosa, *Linn.*	*	*	*h*	*j, k*	*	*	2
207	dichotoma, *Hincks*	*	*					
208	α attenuata, *Alder*	*a*						
209	avicularis, *Hincks*	*a*	?	*h*	*j, k*	*m**		
210	tubigera, *Busk*			*		*		2
211	armata, *Hincks*			*h*	*k*	*m**		
212	Costazii, *Aud.*			*	*	*		3*
213	α tubulosa							
	The following should be with *Porinidæ* (see p. 413, *Hincks*, and should have followed on p. 226).							
52?	Celleporella, *Gray*							
214	lepraloides, *Nor.*	*a*						
215	pygmea, *Nor.*	*a*						

Complete List of British Cyclostomata (Hincks's 'British and Marine Polyzoa').

—	——	*	Coast of France	Mediter. Waters, *Heller*, &c.	Scandinavia and Norway, &c. *Smitt*, *Sars*.	Shetland, Orkney, &c.
		1	2	3	4	5
	SUB-ORDER **CYCLOSTOMATA**					
	Group I. Radicellata, *D'Orb.*					
	Fam. I. **Crisiidæ**					
	Genus Crisia (pt.), *Lamx.*					
216	Crisia cornuta, *Linn.*	**	*	*	*	*
217	α geniculata	S.				
218	eburnea, *Linn.*	**	*	*	*	
219	α aculeata, *Hassall*	W. S.				
220	β producta, *Smitt*					*
221	denticulata, *Lamk.*	**	*	*		
222	α					
	Group II. Incrustata, *D'Orb.*					
	Fam. II. **Tubuliporidæ**					
	Stomatopora, *Bronn.*					
223	granulata, *M.-Edw.*	S. E.	Rosc.[1]			*
223*	major, *Johnst.*	S. E.	Rosc.			*
224	dilatans, *Johnst.*	N. E.	Rosc.		*	*
225	Johnstoni, *Heller*	S.		*		
226	α robusta, *Hincks*					

[1] Roscoff, *Joliet*.
* British range, S. E. N. W., South, East, North, West. ** Distributed all round the coast.

Complete List of British Cyclostomata—continued.

—	—	*	Coast of France	Mediter. Waters, *Heller*, &c.	Scandinavia and Norway, &c. *Smitt*, *Sars*.	Shetland, Orkney, &c.
		1	2	3	4	5
	Fam. II. **Tubuliporidæ**—*cont.*					
	Stomatopora.					
227	expansa ? *Hincks*	W.				
228	incurvata, *Hincks*	W.				
229	diastoporides, *Norman*					*
230	compacta, *Norman*					*
231	incrassata, *Smitt*	S.				*
232	deflexa, *Couch*	S.	Rose.			*
233	fungia, *Couch*	S.				
234	fasciculata ? *Hincks*	W. ?				
	Tubulipora, *Lamk.*					
235	lobulata, *Hassall*	S. W. N.			*	*
236	flabellaris, *Fabric.*	S.		*		*
237	fimbria, *Lamk.*	N.				*
	Idmonea, *Lamx.*					
238	atlantica, *Forbes*			* W. ?		*
239	α tenuis, *Busk*					
240	serpens, *Linn.*	**	*	*	*	
241	α radiata, *Hincks*	S.				
	Entalophora, *Lamx.*					
242	clavata, *Busk*	S. W.				
	Diastopora (pt.), *Lamx.*					
243	patina, *Lamk.*	**	*	* H.	*	*
244	obelia, *Johnst.*	**	*	*		
245	Sarniensis, *Norman*	S.		* ?		
246	suborbicularis, *Hincks*	S. W.		* W.		
	Fam. **Horneridæ**					
	Hornera, *Lamx.*					
247	lichenoides, *Linn.*				*	*
248	violacea, *Sars*				?	*
	Fam. **Lichenoporidæ**					
	Lichenopora, *Defrance*					
249	hispida, *Fleming*	S. N. W.	*		*	*
250	α meandrina, *Peach*					*
251	β					
252	radiata, *Audouin*	S.		*		
253	verrucaria, *Fabric.*				*	*
254	regularis, *D'Orb.*					*
	Domopora, *D'Orb.*					
255	stellata, *Goldfuss*				*	*
256	truncata, *Jameson*					*

Polyzoa (Bryozoa) of Scandinavia. F. A. Smitt.

—	—	British List	1, Southern and 2, Middle Norway	Scandinavian Coast	Spitzbergen	—
	I. CHEILOSTOMATA					
1	Ætea, *Lamx.*					
	anguina, *Linn.*	1	*			
	α spathulata	1	*			
	β recta, *Smitt*	2	*			
2	Eucratea, *Lamx.*					
	Cellularia (Menipea, pt.)					
	ternata, *Sol.*	13		*		
	forma duplex, *Smitt*				*	= Menipea Smittii, *Nor.*
	reptans, *Linn.*	19	1, 2			= Scrupocellaria (pt.)
	scruposa, *Linn.*	15	1, 2			
22	Gemellaria, *Savigny*					
	loricata, *Linn.*	7		*	*	
16	Bicellaria, *Blainv.*					
	ciliata, *Linn.*	22				
17	Bugula, *Oken*					
	avicularia, *Linn.*	24				
	α flabellata	26				
	β fastigiata	31 ?	*			= B. purpurotincta, *Nor.*
	Murrayana, *Johnst.*	32		*	*	
29	Flustra, *Linn.*					
	membranacea, *Linn.*	53 ?				= Membranipora, id. ?
	securifrons, *Pall.*	41		*	*	
	papyrea, *Pall.*	41				
	foliacea, *Linn.*	39	*			
47	Cellaria, *Lamx.*					
	fistulosa, *Linn.*	36				
32	Membranipora, *Blainv.*					
	lineata, *Linn.*	55		*		
	α craticula, *Alder*	56			*	
	β sophiæ, *Busk*					
	γ americana, *D'Orb.*					
	arctica, *D'Orb.*					
	Flemingii, *Busk*	66		*		
	α trifolium, *Wood*	69		*	*	
	pilosa, *Linn.*	49	* ?			
	α monostachys	46				
	β catenularia, *Jam.*	48				
	γ membranacea, *Mull.*	53				
	Escharipora (= Cribrilina, pt.)					
	punctata, *Hass.*	82	*			
	annulata, *Fabric.*	84			*	
	Porina, *D'Orb.*					
	Malusii, *Aud.*	92				
	ciliata, *Pall.*	90				
	Escharella (= Smittia, *Hks.*)					
	Legentilii, *Aud.*	175	*			
	Jacotini, *Aud.*	180	*			
	linearis, *Hass.*	114 ?				
	α biaperta	121				

Polyzoa (Bryozoa) of Scandinavia—continued.

—	—	British List	1, Southern and 2, Middle Norway	Scandinavian Coast	Spitzbergen	—
	I. CHEILOSTOMATA—*cont.*					
3	Mollia, *D'Orb* (pt. Hippothoa)					
	hyalina, *Linn.* . .	134				
	α divaricata . .	145				
74	Myriozoum					
	crustaceum, *Smitt* . .					
	subgracilis, *D'Orb.* .					
65	Lepralia, *Johnst.*					
	hippopus, *Smitt* . .					
64	Eschara					
	cervicornis, *Pall.* . .	168				
	elegantula, *D'Orb.* . .					
68	Escharoides, *M.-Edw.*					
	Sarsii, *Smitt* . . .					
	Discopora					
	coccinea, *Abildg.* . .	193				
	α ovalis, *Hass.* . .					
	Skenii, *Sol.* . . .	197				
83	Cellepora, *Fabric.*					
	ramulosa, *Linn.* . .					
	α tuberosa, *D'Orb.* .					
	Celleporaria					
	incrassata, *Lam.* . .					
57	Retepora, *Imper.*					
	cellulosa, *Linn.* . .					
	α notopachys . .					

Polyzoa (Cheilostomata) of Nova Zembla and the Mouth of the River Yenisi (Kara Sea). F. A. Smitt, *March* 1878.

—	—	British	Nova Zembla	Malotschkin-schare	Beluscha Bay	Kara Sea
			1	2	3	4
	I. CHEILOSTOMATA, *Busk*					
29	Flustra					
	membranaceo-truncata, *Smitt* .			*	*	*
	papyrea, *Pal.*	41		**		
34	Biflustra					
	abyssicola, *Sars*					*
32	Membranipora					
	lineata, *Linn.*	55		*		
	α craticula *Ald.*	56	*	*	*	*
	β unicornis, *Flem.*	61	*	**	*	
	γ americana, *D'Orb.*		*	**		*
17	Bugula, *Oken*					
	Murrayana, *Bean*	32 ?	*	*	*	

* ** Indicate one or more localities.

Polyzoa (Cheilostomata) of Nova Zembla, &c.—continued.

—	—	British	Nova Zembla	Malotschkin-schare	Beluscha Bay	Kara Sea
	I. **CHEILOSTOMATA**—*cont.*		1	2	3	4
10*	Cellularia (= Menipia)					
	ternata, *Ell. & Sol.*	13	*	**		*
	α gracilis, *Van Ben.*			*	*	*
	β duplex, *Smitt*					*
12	Cellularia (= Scrupocellaria)					
	scabra, *Van Ben.*	17				*
	α elongata, *Smitt*					*
	Peachii, *Busk* (= Cellularia)	12		*	*	*
22	Gemellaria					
	loricata, *Linn.*	7		**		*
	Cribrilina, *Gray*					
	punctata, *Hass.*	82				*
	annulata, *Fabric.*	84		*		*
	Porellina					
	ciliata, *Pall.*	90		**		
	Hippothoa					
	biaperta, *Mich.*, *Busk*	121				*
	hyalina, *Linn.*	134	*	**		
74*	Leieschara (= Myrizoum)					
	crustacea, *Smitt*			*	*	*
	subgracilis, *D'Orb.*		*	*	*	*
83	Cellepora					
	ramulosa, *Linn.*	206				
	α tuberosa, *D'Orb.*					*
	incrassata, *Linn.*		*	*	*	
69	Escharella (Smittia, pt.)					
	pertusa, *Busk* (= E. porifera, *Sm.*).	156		*		*
	α majuscula, *Sm.* (= L. Landsborovii, *Ald.*	172?		*	*	*
	palmata, *Sars*			*		*
	Jacotin, *Aud.* (= E. Legentilii, *Aud.*)		*	*	*	*
	Landsborovii, *Johnst.*	172		*		
64	Eschara, *Pallas*					
	cervicornis, *Pall.*	168				
	α verrucosa, *Busk*	168	*	*		*
	β cervicornis, *Pall.*	168		*	*	*
	elegantula, *D'Orb.*		*	*	*	*
	lævis, *Flem.*	169		*	*	*
	Beaniana, *King* (Retepora)	203				
72*	Discopora (Schizoporella, pt.)					
	sincera, *Sm.*			*	*	*
	cruenta, *Nor.*	133		*	*	
	coccinea, *Abldg.*	193				
	α ventricosa, *Hass.* (= Mucronella, id.)	188		**	*	*
	labiata, *Boeck*			*	*	*
	appensa, *Hass.*			*	*	*
	pavonella, *Alder*	195		*		
	scabra, *Fabric.*		*	*		*
	plicata		*	**	*	
	Skenei, *Sol.*	196				*
	Sarsii, *Sm.*		*	**	*	*
	cellulosa, *Linn.*					*
	elongata, *Sm.*			*	*	*

Professor Smitt in the following paper gives a list of localities numbered from 1 to 12.

1. Waideguba = Ajdde-Wuodna in peninsula Ribatschki.
2. Bumanni (l. Bumands.
3. Skarfberget.
4. Subowki.
5. Kola-fjovden (sinu Kola).
6. Semiostrowa.
7. Litza.
8. Kouglaja-juba.
9. Ladigino.
10. Bolschoj-Kletnij.
11. Swiatox-Nos.
12. Lumbowski.

Polyzoa (Bryozoa) in the Arctic Ocean. Kola Peninsula.
F. A. Smitt, *Sept.* 1878.

—	—	British				
	I. CHEILOSTOMATA		1	2	3	4
29	Flustra					
	membranaceo-truncata, *Sm.*		1	12		
	securifrons, *Pall.*	41	1	4		
34	Biflustra					
	arctica, *D'Orb.*		12			
32	Membranipora					
	cymbyaformis, *Hincks*		1	7	12	
	lineata, *Linn.*	55				
	α craticula, *Ald.*	56	1, 4	7, 9	11	12
	β lineata, *Ald.*		1, 6	7, 9	11	
	γ sophiæ, *Busk*		1, 3	7, 10	11	12
	δ unicornis, *Ald.*					12
	ε americana, *D'Orb.*					12
	catenularia, *Jameson*	48	6	9	10	
	α membranacæ, *Mull.*		9			
	pilosa, *Linn.*	49	1	10		
	Mollia, *D'Orb.*					
	Flemingii, *Busk*	66				
	α trifolium, *Wood*	69	9			
37	Bugula, *Oken*					
	Murrayana, *Bean*	32?	1, 2	3, 6	7, 8, 10	12
	quadridentata, *Loven*		4	7		
	avicularia, *Linn.*	24	4			
10*	Cellularia (Menipea)					
	ternata, *Sol.*	13	1	7, 8		
	α arctica, *Busk* = gracilis, *Sm.*		1, 3	4, 5	6, 7	8
	(Scrupocellaria)					
	scabra, *Van Ben.*	17	1, 3	4, 6	7, 9	12
22	Gemellaria					
	loricata, *Linn.*	7				12
15	Caberea					
	Ellisii, *Flem.*	20	1, 3	5, 6	7, 8	9
63	Cribrilina					
	punctata, *Hass.*	82	4			

Polyzoa (Bryozoa) in the Arctic Ocean—continued.

—	—	British	1	2	3	4
	I. CHEILOSTOMATA—*cont.*					
	Cribrilina					
	annulata, *Fabric.*	84	1			
	Porella					
	ciliata, *Pall.*	90	1, 4	7, 9	10, 11	12
	Anarthropora					
	minuscula, *Sm.* (=Lep. tubulosa, *Nor.*)	106	1, 3	11	12	
	Hippothoa					
	auriculata, *Hass.*	125				12
	linearis, *Hass.*	104				12
	biaperta, *Mich.*, *Busk*	121	1	9		12
	secundaria, *Sm.*		1, 3	4, 7	9, 10	
	hyalina, *Linn.*	134	1, 4	7, 9	11	12
	α divaricata, *Lamx.*		1	7, 9	10	
74*	Leischara (=Myriozoum)					
	crustacea, *Sm.*			9	10, 11	12
	coarctata, *Sars*		1	6, 7		
83	Cellepora					
	ramulosa, *Linn.*	206				
	α tuberosa, *D'Orb.*	?	1, 3	4, 7		
	incrassata, *Linn.*		1, 2, 3	4, 5, 6	7, 9	10, 11
	Escharella					
	pertusa, *Esper.*, *Busk*	156	1, 3	4, 6, 7	8, 10	
	porifera, *Sm.*		1, 4	6, 7	9, 11	
	palmata, *Sars*			5		
	Jacotina, *Aud.*, *Sm.*					
	α Legentilia, *Aud.*				9	
	Landsborovii, *Johnst.*	172	1, 2	4, 7	9, 10	
	mucronata, *Sm.*				10	
	Lepralia					
	hippopus, *Sm.*	159	1, 3		9, 10	11
	spathulifera, *Sm.*		1, 3	4, 7	9	
64	Eschara					
	cervicornis, *Pall.*	168				
	α verrucosa, *Thomp.*		1, 3	4, 6	7	11, 12
	β patens, *Sm.*		1	6	7	12
	γ constiformis, *Sm.*		1, 2, 3	4, 5	6, 7	9, 11
	δ erecta, *Sm.*		1, 3	4	7	11
	elegantula, *D'Orb.*				7	
	lævis, *Flem.*	169				
	α concinna, *Busk*		1, 2	3, 4	7, 9	10
	Beaniana, *King* (=Retepora)	203		5		
72*	Discopora					
	sincera, *Sm.*				7	
	cruenta, *Norm.*	133	4			
	megastoma, *Busk*			7, 9	10	
	stenostoma, *Sm.*		4			
	coccinea, *Abild.*	193				
	α Peachii, *Johnst.*	181?	4			
	β ventricosa, *Hass.*	188	1, 3, 4	6, 7	9, 10	
	γ ovalis, *Hass.*		4		10	
	labiata, *Boeck*			5, 7		
	Skenei, *Sol.*	197	4	5		
	pavonella, *Alder*	195	1	5		
	scabra, *Fabric.*		1, 4	6, 7	8, 9, 12	

Polyzoa (Bryozoa) in the Arctic Ocean—continued.

—	—	British	1	2	3	4
	I. **CHEILOSTOMATA**—*cont.*					
	Discopora					
	plicata, *Sm.* . . . . . =(Cellepora bilaminata, *Hks.* ?)		1, 3, 4	6, 7, 8	10, 11	12
	Sarsii, *Sm.* . . . . . (=Lep. radiatula, *Hincks* ?)		3, 6	7, 9	10, 11	
	contigua, *Sm.*		1, 2, 3	4, 6	9, 10	
	rosacea, *Busk*	170		4, 6	7, 9	
	cellulosa, *Linn.*, *Busk* . . .		1, 3	4, 5	6, 7	9
	elongata, *Sm.*		1, 3		6	

1881. *S. W. Ridley on Polyzoa, Franz Josef Land.*

—	—	British, E. W.	Spitzbergen	Barrent's Sea	Kara Sea
	I. **CHEILOSTOMATA**				
	Fam. II. **Eucratiidæ**				
22	Gemellaria loriculata, *Pallas* . . .	7	*	*	*
	Fam. III. **Cellulariidæ**				
10	Menipea arctica, *Busk*			*	
12	Scrupocellaria scabra, *Van Ben.* . .	17	*		*
	Fam. IV. **Bicellaridæ**				
17	Bugula Murrayana, *Johnst.*	32			
	Var. fruticosa, *Pack.*	33 ?			
	Fam. VII. **Flustridæ**				
30	Flustra carbasea, *Ell.* and *Sol.* . .	41	*		
29	securifrons, *Pallas*	41	*		
	Fam. VIII. **Membraniporidæ**				
32	Membranipora sophiæ, *Busk* . . .		*	*	
	craticula, *Alder.*	56	*	*	*
	Fam. **Porinidæ**				
	Anarthropora monodon, *Smitt* . .	106			
74	Myriozoum subgracile, *Smitt* . . .		*	*	*
	crustaceum, *Smitt*		*		*
72	Schizoporella cruenta, *Nor.* . . .	133			
	Fam. XIV. **Escharidæ**				
	Porella concinna, *Busk*	163	*		
	=P. lævis, *Sm.*	169			
70	Mucronella ventricosa, *Hass.* . . .	188			
	Var. connectens, *Ridley* . . .				
68	Escharoides Sarsii, *Smitt* . . .		*	*	*

S. O. Ridley. *Franz Josef Land.*

—	British	Spitz-bergen	Barrent's Sea	Kara Sea
II. CYCLOSTOMATA.				
Crisia denticulata, *Lamk.*	221			
Lichenopora verrucaria, *Fabr.*	253	*	*	*
Heteropora pelliculata, *Waters*				

Polyzoa of the North Polar Expedition (Capt. H. W. Feilden).
George Busk, F.R.S.

—	—	British	H. W. F.	Arctic
	Cellularidæ, *Busk*			
10	Menipea, *Lamx.*			
	gracilis, *Busk*		*	
12	Scrupocellaria, *Van Ben.*			
	scabra, *Van Ben.*	17	*	
	Fam. **Bicellariidæ,** *Busk*			
17	Bugula, *Oken*			
	Murrayana, *Johnst.*	32	*	
	α fruticosa, *Packard*	33 ?	*	
	Fam. **Flustridæ**			
29	Flustra, *Linn.* ? 'British M. Cat.'		*	
	serrulata, *Busk*		*	
	Fam. **Membraniporidæ**			
32	Membranipora, *Blainv.*			
	unicornis, *Alder*			
	Fam. **Escharidæ,** *Busk*			
74	Myriozoum, *Donati*			
	coarctatum, *Sars*		*	
	α subgracile, *D'Orb.*			
64	Eschara (*Busk,* op. cit.)			
	elegantula, *D'Orb.*			
	perpusilla, *Busk*		*	*
	Sarsii, *Smitt*		*	*
	Hemeschara, *Busk*			
	sincera, *Smitt*			
	α inermis, *Busk*			*
	Landborovii, *Johnst.* = Smittia, *Hincks* }	172		
	Fam. **Celleporidæ**			
83	Cellepora, *Fabric.*			
	cervicornis, *Busk*		*	

Polyzoa of Barrent's Sea. Described by Mr. HINCKS *for publication in* Mr. D'URBAN'S *Report on the Zoology of Barrent's Sea (Polyzoa collected by* W. J. A. GRANT), '*Annals,*' *October* 1880, *pp.* 272–275.

Genera only in Report	—	British	Barrent's Sea	—
	I. **CHEILOSTOMATA**, *Busk*			
22	Gemellaria loricata, *Linn.*	7	*	
9	Cellularia Peachii, *Busk*	12	*	
10	Menipia ternata, *Ell.* and *Sol.*	13	*	
	var. gracilis, *Smitt*		*	Menipea gracilis, *Busk*
17	Bugula Murrayana, *Johnst.*	32	*	
29	Flustra, *Linn.*			
	membranaceo-truncata, *Smitt*		*	
32	Membranipora, *Blainv.*			
	monostachys, *Busk*	46	*	
	craticula, *Alder*	56	*	
	sophiæ, *Busk*		*	
	arctica, *Smitt*		*	
63	Microporella, *Hincks*			
	ciliata, *Pallas*	90	*	
	Porina, *D'Orbigny*			
	tubulosa, *Norman*	105	*	
	Myriozoum, *Donati*			
	subgracile, *D'Orb.*		*	
72	Schizoporella, *Hincks*			
	sinuosa, *Busk*	130	*	
	plana, *Dawson*		*	= Myriozoum crustaceum, *Smitt*
	hyalina, *Linn.*	134	*	
78*	Phylactella? *Hincks*			
	grandis, *Hincks*		*	New sp.
70	Mucronella, *Hincks*			
	scutulata, *Busk*		*	
	simplex, *Hincks*			New sp.
64	Eschara, *Pallas*			
	solida, *Stimpson*		*	= Flustra, *id. Stimpson* = E. palmata, *Sars* = Escharella palmata, *Smitt*
	glabra, *Hincks*		*	New sp.
83	Cellepora, *Fabric.*			
	striatula, *Hincks*		*	New sp.?
	II. **CYCLOSTOMATA**, *Busk*			
	Crisia eburneo-denticulata, *Smitt*		*	
	Diastopora obelia, *Johnst.*	244	*	
	Hornera (sp.), *Lamx.*		*	
	Lichenopora verrucaria, *Fabric.*	253	*	

Bryozoa. Scandinavia. SMITT. Pt. II.

—	British	—
II. CYCLOSTOMATA.		
Crisia, *Lamx.*		
cornuta, *Linn.* = Filicrisia, *D'Orb.*	216	
β cornuta = Crisidia, *D'Orb.*		
eburnea, *Linn.* = Crisia, *D'Orb.*		
denticulata, *Lam.*	221	
Diastopora, *Lam.*, *M.-Edw.*		
repens = Alecto, *Busk*	224	
simplex, *Busk*	246	
hyalina	245 ?	
α obelia, *Johnst.*		
β latomarginata, *D'Orb.*		
patina, *Lamk.*	243	
α radiata		
Mesenteripora, *Blainv.*		
meandrina, *Wood*		
Idmonea (sub-genus)		
Tubulipora, *Lamk.*		
atlantica, *Forbes*	238	
α erecta, *Sm.*		
fenestrata, *Busk*		
serpens	240	
α erecta, *Sm.*		
Phalangella, *Gray* (sub-genus)		
palmata, *Wood*		
fimbria, *Lam.*	237	
flabellaris, *Fabr.*	236	
Proboscina, *Aud.* (sub-genus)		
incrassata, *D'Orb.*	231	
α erecta		
β serpens		
penecillata, *Fabr.*		
Hornera, *Lamx.*		
lichenoides, *Linn.*	247	
Discoporella, *Gray*		
verrucaria, *Linn.*	253	
crassiuscula, *Sm.*		
hispida, *Flem.*	249	
Frondipora, *Blainv.*		
reticulata, *Linn.*		
Corymbopora, *Mich.*		
fungiformis, *Sm.*		
Defrancia		
lucernaria, *Sars*		Domopora, *id.*, Report

Cyclostomata of Nova Zembla and Mouth of the River Yenisei (Kara Sea) SMITT. Pt. II.

—	British	Nova Zembla	Malotschakin-schare	Beluscha	Kara Sea
II. CYCLOSTOMATA.					
Crisia					
eburnea, *Linn.*	218	*	*	*	*
α producta, *Sm.*	220				
β eburneo-producta, *Sm.*					*
γ denticulato-producta, *Sm.*			*		*
δ denticulata, *Linn.*	221				*
Diastopora					
repens, *Wood*	224				*
simplex, *Busk*	246				*
hyalina, *Flem.*	245?		* *		*
intricaria, *Sm.*					*
Tubulipora					
fimbria, *Lam.*	237	*			
incrassata, *D'Orb.*	231	*	*		*
incrassata-fungia, *Sm.*					*
fungia, *Couch*	233				*
atlantica, *Forbes*	238		*	*	*
Defrancia					
lucernaria, *Sars*					*
Entalophora					
deflexa, *Couch*					*
Hornera					
violacea, *Sars*					
α proboscina, *Sm.*					*
lichenoides, *Linn.*	247	*			*
Lichenopora					
verrucaria, *Linn.*	253		* *		*

Bryozoa. Arctic Ocean. Kolo Peninsula. SMITT. Pt. II.

—	British	1	2	3	4
II. CYCLOSTOMATA.					
Crisia, *Lamx.*					
eburnea, *Linn.*	218	1		8	
α producta, *Sm.*	219	1			
β eburneo-producta		1			
γ denticulata	221		4		
Diastopora					
repens, *Wood*			4	7	
simplex, *Busk*		1	6, 7	9, 11	12
diastoporides, *Norm.*	229	1			
hyalina, *Flem.*			4, 7		11, 12
intricaria, *Sm.*			5		
Tubulipora					
palmata, *Wood*		1, 4			

Bryozoa. Arctic Ocean: Kolo Peninsula—continued.

—	British				
		1	2	3	4
II. CYCLOSTOMATA—*cont.*					
Tubulipora					
fimbria, *Lam.*	237	1, 4?		7	
flabellaris, *Fabric.*	236	1			
incrassata, *D'Orb.*	231	1, 4		8, 9	
serpens, *Linn.*	240			7	
atlantica, *Forbes*	238	1, 3	5, 6	7, 8	
Defrancia					
lucernaria, *Sars*			4		
Coronopora					
truncata, *Jameson*	256		4		
Hornera					
lichenoides, *Linn.*	247	1, 4	5		
Lichenopora					
verrucaria, *Linn.*	253	1, 3	4, 7	11	12
crassiuscula, *Sm.*				9	
III. CTENOSTOMATA.					
Alicyonidium					
gelatinosam, *Linn.*			5		
papillosam, *Hass.*		1, 4			
Vesicularia					
uva, *Linn.*					12

A. *North Atlantic Region. Between parallels* 70° *W. and* 20° *E. Bathymetrical Distribution, 'Challenger.'*

Genera in Report	—	Over 2,500 fath.	2,500 to 2,000 fath.	1,950 to 1,675 fath.	1,525 to 900 fath.	450 to 390 fath.	120 to 10 fath.	Shallow water	Geographical distribution
28	Farciminaria delicatissima	*	*	*					
	gracilis			*					B.
	atlantica					*			
17	Bugula reticulata								
	var. unicornis		*	*					
	mirabilis		*						
	leontodon				*				
	versicolor					*			B.
	neritina						*		
18	Kinetoskias cyathus				*				B.
45	Bifaxaria reticulata		*	*					
	minuta			*					
47	Salicornaria magnifica			*					B. C.
76	Tessaradoma boreale			*		*			
13	Canda simplex			*					
10	Menipea clausa			*					
14	Nellia simplex			*					
12	Scrupocellaria Macandrei				*			*	
9	Cellularia biloba				*				
30	Carbusea pedunculata				*	*			
26	Brettia cornigera					*			

A. *North Atlantic Region*—continued.

Genera in Report	—	Over 2,500 fath.	2,500 to 2,000 fath.	1,950 to 1,675 fath.	1,525 to 900 fath.	450 to 390 fath.	120 to 10 fath.	Shallow water	Geographical distribution
4	Pasythea eburnea . .					*			B.
3	Hippothoa divaricata .					*			C.
32	Membranipora albida .					*			D.
	galeata . . .								
	var. multifida . .					*			B.
38	Micropora coriacea . .					*			
81	Adeonella distoma . .					*			
57	Retepora Imperati . .					*	*		
	atlantica . . .					*			
60	Cribrilliina radiata . .					*			
62	Flustramorpha hastigera .					*			
69	Smittia oratavensis . .					*			
	Jacobensis . . .						*		
70	Mucronella canalifera .					*			
83	Cellepora ansata . .					*			
	ovalis					*			
	canaliculata . .						*		
67	Porella lævis . . .								
	var. subcompressa .						*		
64	Eschara elegantula .						*		
1	Aetea anguina . . .						*		C. D. G.
31	Diachoris hirtissima .						*		
84	Cupularia Owenii . .						*		
8	Catenaria diaphana . .							*	
49	Tubucellaria opuntioides .							*	

PART II.

Mediterranean and South Atlantic Regions.

Polyzoa (Bryozoa) of the Bay of Naples and other Mediterranean Forms.
A. W. Waters, Esq., F.G.S.; Dr. Manzoni; Prof. Cam. Heller.

—	—	Brit.	B. Nap.	Adr.	Æg. or Med.	Red S.	—
	CHELOSTOMATA						
	Fam. **Aeteidæ**						
1	Aetea, *Lamx.*						
	recta, *Hincks* . .	2	* W				
	Fam. **Eucratiidæ**						
2	Eucratea, *Lamx.*						
	chelata, *Linn.* . .	4			* ?		
	Lafontii, *Aud.* . .		* W	*			
	Cordieri, *Aud.* . .		?		* ?	*	
	Fam. **Cellulariidæ**						
12	Scrupocellaria, *Van Ben.*						
	scruposa, *Linn.* . .	15	* W	*	*		
	scrupea, *Busk* . .	18	* W	*	*		
	reptans, *Linn.* . .	19	* W	*		?	

Polyzoa (Bryozoa) of the Bay of Naples, &c.—continued.

—	—	Brit.	B. Nap.	Adr.	Æg. or Med.	Red S.	—
	Fam. **Cellulariidæ**—*cont.*						
15	Caberea, *Lamx.*						
	Boryi, *Aud.* . .	21	* W	*	*		
	Fam. **Bicellariidæ**						
17	Bugula, *Oken*						
	avicularia, *Linn.* .	24	* W	*			
	flabellata, *J. V. Thomp.*	26	* W	*			
	plumosa, *Pall.* . .	28	* ?	*			=? fastigiata, *Wat.*
20	Beania, *Johnst.*						
	mirabilis, *Johnst.* .	34	* W	* =			
47	Cellaria, *Lamx.* (part)						
	fistulosa, *Linn.* . .	36	* W	*	*		
	Flustra, *Linnæus*						
	securifrons, *Pall.* .	41	* W	*	*		
	papyrea, *Pall.* . .		* W	*			
31	Diachoris, *Busk*						
	patellaria, *Moll.*, *Waters* . .		* W	*			
	multijuncta, *Waters* .		* W	* ?			
	magellanica, *Busk* .		* W	*			
	Fam. **Membraniporiidæ**						
32	Membranipora, *Blainv.*						
	Lacroixii, *Aud.* . .	45			*		
	catenularia, *Jameson* .	48	?	*			
	pilosa, *Linn.* . .	49	?	*	*		
	membranacea, *Linn.* .	53	* W	*			
	lineata, *Linn.* . .	55		*			
	Dumerilii, *Aud.* .	62			* ?		
	? Flemingii, *Busk* .	66		*			? M. tenuirostris, *H.*
	Rosselii, *Aud.* . .		?	*			
	angulosa, *Reuss.* .		* W				
	gregaria ? *Heller*, *Waters* . .		* ?	*			
	Fam. **Microporidæ**						
	Steganoporella, *Sm.*[1]						
	impressa, *Moll.* (*Micropora*, *W.*) .	76 ?	* W	*			
	Fam. **Cribrilinidæ**						
60	Cribrilina, *Gray*						
	radiata, *Moll.* . .	78	*	*	*		
	figularis, *Johnst.* .	85		*			
	Gattyæ, *Busk* . .	86	* W	*			
	cribrosa, *Heller* . .		* W				
	Fam. **Microporellidæ**						
63	Microporella, *Hincks*						
	ciliata, *Pallas* . .	90	*	*			
	Malusii, *Aud.* . .	92	*	*	*		

[1] Eschara impressa (Moll.) is a *Steganoporella* (Hincks, p. 215, note).

Polyzoa (Bryozoa) of the Bay of Naples, &c.—continued.

—	—	Brit.	B. Nap.	Adr.	Æg. or Med.	Red S.	—
	Fam. **Microporellidæ**—*cont.*						
	Microporella						
	impressa, *Moll.*	95					
	var. α, *Hincks, Moll., Waters*	96	* W				
	violacea, *Johnst.*	99	*	*			
	Diporula, *Hincks*						
	verrucosa, *Peach*	102	*				
66	Chorizopora, *Hincks*						
	Brongniartii, *Aud.*	103	*	*	*		
	Fam. **Porinidæ** (pt.), *D'Orb.*						
	Porina, *D'Orb.*						
	cereoides (*Wat.*, Bay of Nap.		*				
	Fam. **Myriozoidæ**, *Smitt*						
72	Schizoporella, *Hincks*						
	unicornis, *Johnst.*	108	*	*			
	spinifera, *Johnst.*	110		* =			
	vulgaris, *Moll.*	112	*	*			
	linearis, *Hass.*	114		*	*		
	γ nitida, *Hincks*	117 ?					
	sanguinea, *Norman*	119	* W				
	auriculata, *Hass.*	112	* W		*		
	var. β cuspidata	127				* ?	
	Cecilii, *Aud.*	132	*	*			
62*	Mastigophora, *Hincks*						
	Dutertrei, *Aud.*	139				*	
	Hyndmanni, *Johnst.*						
	var. porosa, *Pourtalès*					* ?	
54 ?	Schizotheca, *Hincks*						
	fissa, *Busk*	143	*				
3	Hippothoa, *Lamx.*						
	divaricata, *Lamx.*	145			*		
	flagellum, *Manzoni*	150			*		
	Fam. **Escharidæ** (pt.) *Smitt*						
65	Lepralia, *Johnst.* (pt.)						
	Pallasiana, *Moll.*	151	* W	*	*		
	foliacea, *Ellis* and *Sol.*	153	*	*	*		
	var. α fasciales, *Waters*		*				
	pertusa, *Esper.*	156		*			
	adpressa, *Busk*	157	*				
78 ?	Umbonula, *Hincks*						
	verrucosa, *Esper.*	162		* =			
67	Porella, *Gray*						
	concinna, *Busk*	163		* =			
69	Smittia, *Hincks*						
	reticulata, *Macgil.*	175		*	*		
	trispinosa, *Johnst.*	180		*			
70	Mucronella, *Hincks* (= Discopora, *Sm.* pt.)						
	Peachii, *Johnst.*	185		* =			

Polyzoa (Bryozoa) of the Bay of Naples, &c.—continued.

—	—	Brit	B. Nap.	Adr.	Æg. or Med.	Red S.	—
	Fam. **Escharidæ**—*cont.*						
	Mucronella						
	ventricosa, *Hass.* .	188			* *Manz*		
	variolosa, *Johnst.* .	189		* =			
	coccinea, *Abildg.* .	193		*			
57	Retepora, *Imperato*						
	Couchii, *Hincks* .	204			*		
	cellulosa . . .		* W				
	Fam. **Celleporidæ**						
83	Cellepora, *Fabr.* pt.						
	pumicosa, *Linn.* .	205		*	*		
	Costazii, *Aud.* . .	212	*			*	
	verruculata . .		* W				

Cyclostomata, Bay of Naples, A. W. Waters. *Adriatic Sea. (See Bibliography.)*

—	British	Bay of Nap.	Adr.	—
Crisia cornuta, *Linn.*	216	*		rare
producta, *Smitt*	220	*		rare
fistulosa, *Heller*		*	*	
elongata, *M.-Ed.*		*	*	= C. attenuata, *Heller*
var. angustata, *Wat.* . .		*		
denticulata, *Lamx.*	221	*	*	
eburnea, *Linn.*	218	*	*	
recurva, *Heller*			*	
Idmonea atlantica, *Forbes* . .	238	*		{ Naples, 40 fath. Only one piece
marionensis, *Busk*		*		
irregularis, *Menegh.*		*	*	
Meneghinii, *Heller*		*	*	
triforis, *Heller*		*	*	
concava, *Reuss*		*		
frondosa, *Heller* . . }			*	{ These are given by *Heller* (non *Waters*)
gracilis, *Heller* . . }			*	
serpula, *Heller* . . }			*	
tubulipora, *Heller* . . }			*	
Tubulipora serpens, *Linn.* . . .	240	*	*	= Obelia tubulifera, *Heller*
phalangea, *Couch*	236	*	*	{ = T. flabelaris, *Hincks* = T. verrucaria, *Heller*
incrassata, *D'Orb.*	231	*		= Stomatopora, *Hincks*
Diastopora latomarginata, *D'Orb.* .		*	*	{ = Discosparsa complanata, *Heller*
flabellum, *Reuss*	246	*		
obelia, *Johnst.*	244	*	*	
Alecto repens, *Wood*		*		{ ? Stomatopora dilatans, *Hincks*
var. *a*, *Waters*		*		
parasita, *Heller*	223		*	{ = Stomatopora granulata, *Hincks*
Entalophora proboscidæ, *Forbes* .		*	*	Pustulopora, *id.*, *Heller*
deflexa, *Couch*	242?	*	*	„ deflexa, *Heller*
rugosa, *D'Orb.*		*		

Cyclostomata, Bay of Naples—continued.

—	British	Bay of Nap.	Adr.	—
Hornera frondiculata, *Lamx.*		*	*	
Filisparsa tubulosa, *Busk*		*		= Hornera violacea, *var.* β tubulosa, *Busk*
Discoporella radiata, *Aud.*	252	*	*	= Discosparsa patina, *Heller*
verrucaria, *Fabr.*		*		
hispida, *Flem.*	249	*		
mediterranea, *Blainv.*		*		
Radiopora pustulosa, *D'Orb.*		*		
Reticulipora dorsalis, *Waters*		*		
Frondipora verrucosa, *Lamx.*		*		
Myriozoum truncatum, *Don.*			*	

Madeira Species of Polyzoa. George Busk, Esq., F.L.S., *and* Rev. Thomas Hincks.

—	—	Brit.	Busk	Hincks	Medit.	—
	Fam. **Aetidæ**, *Hincks*					
1	Aetea, *Lamx.*					
	recta, *Hincks*	2		*	*	
	truncata, *Landsb.*	3	*			
	Fam. **Eucratiidæ**					
2	Eucratea, *Lamx.*					
	Lafontii, *Aud.*		*		*	
	Fam. **Cellularidæ**					
12	Scrupocellaria					
	scabra, *Van Ben.*	17	*			= S. Delilii, *Busk*
	Maderensis, *Busk*		*			
	Macendrei, *Busk*		*			
	diaphana, *Busk*		*			= Scruparia, *id. Busk*
	Fam. **Bicellariidæ**					
17	Bugula, *Oken*					
	avicularia, *Linn.*	24 ?	*		*	
	gracilis, *Busk*	29 ?	*			
	ditrupa, *Busk*		*			
	Fam. **Cellariidæ**					
47	Cellaria, *Lamx.*					
	Johnsoni, *Busk*	38	*			
	Fam. **Flustridæ**					
29	Flustra, *Linn.*					
	ligulata, *Busk*		*			= Carbasea, *id. Busk*
	Fam. **Membraniporidæ**					
32	Membranipora, *Blainv.*					
	tuberculata, *Bosc.*		*			

Madeira Species of Polyzoa—continued.

—	—	Brit.	Busk	Hincks	Medit.	—
	Fam. **Membraniporidæ**—*cont.*					
	Membranipora					
	trichophora, *Busk*		*			
	antiqua, *Busk*		*			
	Lacroixii, *Aud.*	45	*		*	
	lineata, *Linn.*	55	*		*	
	calpensis, *Busk*		*			
	Rosselii, *Aud.*	68	*		*	
	sceletos, *Busk*		*	*		Lepralia, *id. Busk*
	Dumerilii, *Aud.*	62				? L. Pouellelii, *Busk*
	tenuirostris, *Hincks*			*	*	= M. Flemingii, *Waters*
	nodulifera, *Hincks*			*		
	crassimarginata, *Hincks*			*		
	granulifera, *Hincks*			*		
	Fam. **Microporidæ**					
43	Setosella, *Hincks*					
	vulnerata, *Busk*	77		*		
	Fam. **Cribrilinidæ**					
60	Cribrilina, *Gray*					
	radiata, *Moll.*	78	*	*	*	= Lepralia, *id. Busk*, & L. innominata, *Johnst*
	punctata, *Hass.*			*		
61	Membraniporella					
	nitida, *Johnst.*	88		*		
	Fam. **Microporellidæ**					
63	Microporella, *Hincks*					
	decorata, *Reuss*			*		Near M. violacea, *Johnst.*
	Malusii, *Aud.*	92		*	*	
66	Chorizopora, *Hincks*					
	Brongniartii, *Aud.*	103			*	
	Fam. **Myriozoidæ**, *Smitt*					
72	Schizoporella, *Hincks*					
	sanguinea, *Norman*	119		*	*	
	biaperta, *Michelin*	121		*		
	auriculata, *Hass.*	125		*	*	
	armata, *Hincks*	124		*		
	venusta, *Norman*	128		*		
	discoidea, *Busk*	129	*			Lepralia, *id. Busk*
	vulgaris, *Moll.*	112	*		*	= L. alba, *Hincks, Busk*
	unicornis, *Johnst.*	108	*		*	
	Mastigophora, *Hincks*					
	Dutertrei, *Aud.*	139	*		*	= L. Woodiana, *Busk*
	Hyndmanni, *Johnst.*	142		*	*	
	Fam. **Escharidæ**					
65	Lepralia, *Johnst.* (pt.)					
	Pallasiana, *Moll.*	151		*	*	
	Kirchenpaueri, *Heller*					
	Var. teres, *Hincks*			*		
	adpressa, *Busk*	157		*	*	
	pertusa, *Esper.*	156		*	*	

Madeira Species of Polyzoa—continued.

—	—	Brit.	Busk	Hincks	Medit.	—
	Fam. **Escharidæ**—*cont.*					
67	Porella, *Gray*					
	nitidissima, *Hincks* .			*		
	concinna, *Busk* . .	163	*		*	Lepralia, *id. Busk*
69	Smittia, *Hincks*					
	marmorea, *Hincks* .	178		*		
	Phylactella, *Hincks* . .					
	labrosa, *Busk* . .	182		*		
	lucida, *Hincks* . .			*		
	Fam. **Celleporidæ**					
83	Cellepora, *Fabric.* . .					
	Costazii, *Aud.* . .	212	*		*	=C. Hassallii, *Busk*

Floridan Bryozoa. T. A. Smitt, 1872–3. Pt. II.

—	—	Brit.	Floridan	Brit.	—
32 (pt.)	Membranipora, *Blainv.* .				
	lineata, *Linn.* (p. 7) .	55	*	*	=Membranipora, id. *Hks.*
	canariensis, *Sm.* (p. 10)		*		
61 (pt.)	Membraniporella (p. 11) .				
	Agassizii, *Sm.* (p. 11) .		*		
	nitida, *Johnst.* (p. 10) .	88	*	*	
40 (pt.)	Steganoporella (p. 15) .				
	elegans, *M.-Edw.* .		*		=Steganoporella magnilabris, *Bk.*
	Rozieri, *Aud.* (p. 16) .		*		=Setosella *Hks.*
43 (pt.)	Cupularia (p. 14) . .				
	umbellata, *Defr.* . .		*		
	domo, *D'Orb.* (p. 15) .		*		
34	Biflustra, *D'Orb.* (p. 18) .				
	Lacroixii . . .	45	*	*	
	denticulata . . .		*		
	Savartii, *Aud.* . .		*	*	
17 (pt.)	Bugula (p. 18) . . .				
	avicularia . . .	26	*	*	=Bugula flabellata, *W. J. Thomp.*
60	Cribrilina (p. 22) . .				
	radiata, *Moll.* . .	78	*	*	
	innominata, *Couch.* .	78	*	*	
63	Porellina (p. 26) . .				
	ciliata	90	*	*	
63	Porina (p. 30) . . .				
	violacea . . .	99	*	*	=Microporella, id. *Hks.*
	plagiopora . . .	101	*	var. β	= " "
	Tessaradoma (p. 32) .				
	borealis . . .	104	*		=Porina borealis, *Hks.*
	Anarthropora . . .				
	minuscula, *Sm.* . .	106	*	*	=Anarthropora monodon, *Hks.*
	Mamillopora (p. 32) . .				
	cupula . . .		*		

Floridan Polyzoa—continued.

—	—	Brit.	Floridan	Brit.	—
4	Gemellipora (p. 35) . .				
	eburnea . . .		*		
	glabra				
	= var. striatula (p. 37)		*	*	= Schizoporella venusta, *Hks.*
	Hippothoa (pp. 41–44) .				
	porosa	142	*	*	= Mastigophora Hyndmani, *Hincks*
	Isabellina, *D'Orb.* .				
	biaperta (p. 46) . .	121	*	*	= Schizoporella biaperta, *H.*
	divergens (p. 47) .	121	*	*	= " "
69 (pt.)	Escharella (p. 54) . .				
	sanguinea *Norm.* .	119	*	*	
	pertusa, *Esper.* (p. 55)	156	*	*	= Lepralia, id.
	Audouinii, *Sm.* (p. 56)				
	Landsborovi (p. 60) .	172	*	*	= Smittia Landsborovii, *Hks.* p. 342
	Jacotina (p. 59) . .	180	*	*	= Smittia trispinosa, *Hks.* p. 353
	Lepralia (p. 61) . .				
	inornata . . .		*		
	edax, *Bk.* (p. 63) .	160	*	*	= Lepralia, id. *Hks.* p. 311
57	Retepora (p. 67) . .				
	marsupiata, *Sm.* . .		*		
	reticulata, *Pourtalès* .		*		
70	Discopora (p. 67) . .				
	albirostris, *Sm.* (p. 70)		*		
83	Cellepora (p. 53) . .				
	avicularia . . .	207	*	*	= Cellepora dichotoma, *H.* p. 403

The Polyzoa of the Straits of Magellan and Coast of Patagonia, &c. (*'Alert' Expedition*). STUART O. RIDLEY.

—	—	British	Magellan	Brazilian	Patagonian	—
	Fam. **Cellularidæ**					
13	Canda = ? *Scrupocellaria* . Sp. *Ridley*, Victoria Bank			*		
	Fam. **Bicellariidæ**, *Hincks*					
	Chaunosia fragilis, *Ridley* .					Near Beania[1]
	Fam. **Membraniporidæ**					
32	Membranipora, *Blainv.* .					
	Lacroixii, *Aud.* . .	45		*		
	curvirostris, *Hincks* .	60		*		

[1] See Hincks 'Ann. Mag. Nat. Hist.' Aug. 1881, p. 133.

The Polyzoa of the Straits of Magellan, &c.—continued.

—	—	British	Magellan	Brazilian	Patagonian	—
	Fam. **Cribrilinidæ**					
60	Cribrilina, *Gray* . .					
	radiata, *Moll.* . .	78		*		
	Fam. **Microporellidæ**					
	Gigantopora, *Ridley* . .					
	lycoides, *Ridley* . .			*		S. O. Ridley believes that *Hippothoa fenestrata* (Smitt) should be referred to this genus
	Fam. **Porinidæ**					
	Porina, *D'Orb.* . . .					
	galeata, *Busk* . .		*			
	Myriozoidæ, *Smitt*					
72	Schizoporella, *Hincks* .					
	marsupium, *Macgil.* .		*			= Lepralia, id. *Macgil.*
	hyalina, *Linn.* . .	134	*			
	β incrassata, *Hincks* .	136?	*			
	γ tuberculata, *Hincks*	137?	*			
	spinifera, *Johnst.*? .	110				Tom Bay, S.W. Chili
	sp. *Ridley* . .					Ditto
	labiosa, *Busk* . .		*			
	Fam. **Escharidæ** (pt.) *Smitt*					
65	Lepralia, *Hincks* . .					
	monoceros, *Busk* . .		*			
	appresa, *Busk* (*Ridley*)					
	var. vinosa, *Ridley* .					Portland Bay, S.W. Chili
69	Smittia, *Hincks* . .					
	Landsborovii, *Johnst.* .	172	*			
	reticulata, *Macgil.* .	175	*			
	affinis, *Hincks* . .	176	*			
	trispinosa, *Johnst.* .	180		*		
53?	Rhyncopora, *Hincks* . .					
	bispinosa, *Johnst.* . .	202		*		
57	Retepora, *Imp.* . . .					
	cellulosa, *Oken*? . .		*			
	altisulcata, *Ridley* .					Tom Bay, S.W. Chili
	Fam. **Celleporidæ**					
83	Cellepora, *Fabric.* . .					
	tubigere, *Busk* . .	210			*	Madre de Dios Island
	bilabiata, *Busk* . .		*			
	mamillata, *Busk* . .			*		
	turrita, *Smitt* . .			*		
	dichotoma, *Hincks* .	207		*		

B. *South Atlantic Region. From 70° W. to 20° E.*

Genera in Report	Bathymetrical Distribution	Over 2,500 fath.	2,200 to 1,900 fath.	600 fath.	360 to 350 fath.	150 to 70 fath.	55 to 18 fath.	12 to 5 fath.	Geographical distribution
9	Cellularia crateriformis	*	*						
18	Kinetoskias cyathus	*							A.
	pocillum				*				G.
28	Farciminaria magna	*							C.
	var. armata		*						
	cribraria		*						
	gracilis				*				
	brasiliensis				*				
16	Bicellaria navicularis		*		*				
	glabra						*		
17	Bugula margaritifera		*						
	reticulata			*					
	versicolor				*				
47	Salicornaria magnifica		*		*				A. C.
	variabilis					*			
	tenuirostris					*			
	dubia			*					
	Malvinensis							*	C. D. G.
15	Caberea crassimarginata			*					
	Darwinii				*	*			C.
	minima							*	
32	Membranipora galeata								
	var. erecta			*					
	var. multifida						*		
	crassimarginata								
	var. incrustens				*				
19	Ichyaria oculata			*		*			
35	Foveolaria elliptica			*					D.
	falcifera			*					
	tubigera						*		
39	Vincularia labiata			*					
45	Bifaxaria denticulata			*					
	submucronata				*				
	corrugata				*				
48	Melicerita atlantica			*					
	dubia			*					
57	Retepora Magellensis			*					
	tessellata						*		
	var. pubens					*			
	var. cæspitosa						*		
	latæ						*		
59	Turritigera stellata			*		*			
60	Cribrilina latimarginata			*					
	radiata				*				
	monoceros						*	*	C. D. F. G.
	labiosa								
	var. fragiles						*		
69	Smittia Smittiana			*					
	tenuis						*		
	stigmatophora							*	
74	Myriozoum immersum			*					
	simplex			*					
1	Aetea anguina				*				
3	Hippothoa divaricata				*				A
7	Catenicella elegans				*				D
	sacculata				*				

B. *South Atlantic Region*—continued.

Genera in Report	Bathymetrical Distribution	Over 2,500 fath.	2,200 to 1,900 fath.	600 fath.	360 to 350 fath.	150 to 70 fath.	55 to 18 fath.	12 to 5 fath.	Geographical distribution
12	Scrupocellaria pilosa				*				
38	Micropora uncifera				*				
	coriacea				*				
63	Microporella ciliata				*				
	Malusii				*			*	
65	Lepralia incisa				*				
	margaritifera							*	
	marsupium							*	
66	Chorizopora hyalina								
	var. Bougainvillei				*				
	Brongniartii						*		
71	Aspidostoma giganteum				*				
72	Schizoporella auriculata								
	var. alba				*				
	tenuis						*		
	nivea					*			
	elegans					*			
	circincta				*				
75	Haswellia auriculata				*	*			
81	Adeonella atlantica				*				
	distoma								
	var. imperforata				*				
	regularis					*			
83	Cellepora tubulosa				*				
	aspera				*				
	cylindriformis					*			
	bicornis					*	*		
	imbellis						*		
	mamillata								
	var. atlantica						*		
	Etonensis							*	
	Simonensis						*		
	conica						*		
4	Pasythea eburnea				*				
45	Bifaxaria corrugata				*				
	submucronata				*				
70	Mucronella castanea				*		*		
	contorta						*		
	tricuspis						*	*	
10	Menipea marionensis					*			
	benemunita					*	*	*	
	flagellifera					*	*		
	flabellum						*		
	triseriata						*		
	cirrata						*		
	aculeata							*	
30	Carbasia ovoidea							*	
	elegans						*		
77	Gemellipora glabra						*		
	cribritheca						*		
33	Amphiblestrum imbricatum						*		
	capense						*		
56	Onchoporella bombycina						*		
84	Cupularia monotrema						*		
14	Nellia occulata						*		

PART III.

Geographical Range of Australian, Pacific, and Indian Polyzoa.

The lists headed A to G compiled from Mr. Busk's monograph ('Challenger' Report on Polyzoa).

Australian Polyzoa. P. H. Macgillivray, M.A., M.R.C.S.

The following list of Macgillivray's Australian species has been compiled for me from various sources—some of which are inaccessible to me—by Miss E. C. Jelly. I have arranged the genera, as far as possible, in accordance with the present catalogue.

I. **CHEILOSTOMATA**, *Busk.*

Fam. IV. **Catenariadæ**, *Busk.*

Gen. 7. Catenicella, *Blainville.*
 gracilenta, *Macgillivray.*
 intermedia ,,
 Wilsoni ,, Port Phillip Heads.
 utriculus ,,
 fusca ,,
 concinna ,, ,, ,,
 pulchella, *Maplestone,* Jour. Micro. Soc. Vict. May, 1880
 = C. concinna, *Macgil.* ? = C. Wilsoni, *Macgil.*
 amphora, *Busk,* M'Coy's, Decade IX. and Brit. Mus. Cat. pt. I.
Alisidota (= ? Catenaria, *Busk, Savigny*).
 ciliata, *Macgil.* ? = C. Wilsoni, *Macgil.*

Fam. V. **Cellulariadæ.**

Menipea, *Lamx.*
 cervicornis, *Macgil.*
Scrupocellaria, *Van Ben.*
 obtecta, *Haswell.* Port Phillip Heads.
Canda, *Lamx.*
 tenuis, *Macgil.*

Fam. VI. **Bicellariadæ.**

Bugula, *Oken.*
 robusta, *Macgil.*
Beania, *Johnston.*
 Beania
 decumbens, *Macgil.*
 Wilsoni, *Macgil.*

Fam. VIII. **Gemellariadæ.**

Family (? *Macgil.*)
Urceolipora, *Macgil.* ? = Ichthyria sp. *Busk.*
 nana, *Macgil.* Port Phillip Heads.
 dentata, *Macgil.*

Maplestonia, *Macgil.* (Family ?)
 cirrata, *Macgil.*
 simplex, *Macgil.*

Fam. XI. **Membraniporidæ.**

Membranipora, *Blainville.*
acifera, *Macgil.*
flagellum, *Macgil.*
papulifera, *Macgil.*
albispina, *Macgil.*
serrata, *Macgil.*
armata, *Macgil.*
bimamillata, *Macgil.*

Membranipora
porcellana, *Macgil.*
Woodsii, *Macgil.*
dispar, *Macgil.*
ciliata, *Macgil.*
Biflustra, *D'Orb.*
perfragilis, *Macgil.* Port Phillip Heads.

Fam. XV. **Salicornariadæ,** *Busk.*

Salicornaria Cuvier (*Cellaria*) *Macgil.*
rigida, *Macgil.* Port Phillip Heads.
australis, *Macgil.*

Fam. XVI. (*a.*) **Porinidæ,** *Hincks.*

Lagenipora, *Hincks.*
tuberculata, *Macgil.*

Fam. XVI (*b.*) **Myriozoidæ,** *Hincks.*

Rhynchopora, *Hincks.*
profunda, *Macgil.*
Porina, *D'Orb.*
magnirostris, *Macgil.* Port Phillip Heads.
gracilis, *Lamk.* „ „

Fam. XVIII. **Reteporidæ,** *Busk.*

Retepora, *Imperato.*
carinata, *Macgil.*
monilifera, *Macgil.*
var. sinuata, *Macgil.* = R. sinuata, *Busk.*
form umbonata, *Macgil.* = R. umbonata, *Busk.*
form munita, *Macgil.* = R. munita, *Busk.*
var. lunata, *Macgil.* = R. lunata, *Busk.*
„ acutirostris, *Macgil.* = R. acutirostris, *Busk*
Petralia, *Macgil.*
undata, *Macgil.* Port Phillip Heads.

Fam. XIX. **Cribrilinidæ.**

Cribrilina, *Gray.*
setirostris, *Macgil.*
monoceros, *Macgil.* Port Phillip Heads.
Membraniporella, *Smitt.*
distans, *Macgil.*

Fam. XX. **Microporellidæ.**

Microporella, *Hincks.*
renipuncta *Macgil.*
Malusii, *Aud.*
var. personata, *Macgil.*

Microporella
 scandens, *Macgil.*
 diadema, *Macgil.*
  var. lunipunctata, *Macgil.*
  „ longispina, *Macgil.*
  „ lata, *Macgil.*
  „ caniculata, *Macgil.*

Fam. XXI. **Escharidæ**

Dictyopora, *Macgil.*
 albida, *Kirchenpauer* (Adeona, *id.*)
  var. avicularis, *Macgil.*
 Wilsoni, *Macgil.* Port Phillip Heads.
Eschara, *Pallas.*
 obliqua, *Macgil.*
 dispar, *Macgil.*
 quadrata, *Macgil.*
 mucronata, *Macgil.*
 elegans, *Macgil.*
Lepralia (*Johnston ?*) *Macgil.*
 anceps „
 Maplestonii „
 vittata „
 elegans „
 lunata „
 trifolium „
 cheilidon „
 caniculata „
 larvalis „
 papillifera „
 Ellerii „
 excavata „
 vitrea „
Lepralia
 megasoma, *Macgillivray.*
 schizostoma „
 botryoides „
 ferox „
 pellucida „
 ceramia „
Porella, *Gray.*
 marsupium, *Macgil.* Port Phillip Heads.
Smittia, *Hincks.*
 oculata, *Macgil.*
 reticulata,
  Var. spathulata, *Macgil.*
Mucronella, *Hincks.*
 munita, *Macgil.*
 lævis, *Macgil.*
 seriatula, *Macgil.*
Schizoporella, *Hincks.*
 lata, *Macgil.*
 insignis, *Macgil.*
 punctigera, *Macgil.*
 magnirostris, *Macgil.*
 Ridleyi, *Macgil.*
 arachnoides, *Macgil.*
 cryptostoma, *Macgil.*

Fam. XXIII. **Celleporidæ.**

? Lekythopora, *Macgil.*
 hystrix, *Macgil.*
Cellepora, *Fabr.*
 munita, *Macgillivray.*
 longirostris „
 platalea „
 serratirostris „
Cellepora
 megasoma, *Macgillivray.*
 rota „
 costata „
 variolosa „
 intermedia „
 exigua „

CYCLOSTOMATA, *Busk.*

Crisidæ, *Milne-Edw.*
Crisia, *Lamk.*
Crisia
 tenuis, *Macgil.*

Tubuliporidæ.

Tubulipora, *Lamk.*
concinna, *Macgil.*
pulchra, *Macgil.*
connata, *Macgil.*
clavata, *Macgil.*
lucida, *Macgil.*
Entalophora, *Lamx.*
regularis, *Macgil.* (Pustulopora).
Idmonea, *Lamx.*
Milneana, *D'Orb.*
australis, *Macgil.*
Diastopora, *Lamx.*
lineata, *Macgil.*
fasciculata, *Macgil.*
bicolor, *Macgil.*
Densipora, *Macgil.*
corrugata, *Macgil.*
Horneridæ, *Smitt.*
Hornera, *Lamx.*
robusta, *Macgil.*
foliacea, *Macgil.*
Lichenoporidæ, *Smitt.*
pristis, *Macgil.*
(= Discoporella).
reticulata, *Macgil.*
(= Discoporella).
echinata, *Macgil.*
(= Discoporella).
? Favosipora, *Macgil.*
rugosa, *Macgil.*
Frondiporidæ, *Smitt.*
Fasciculipora, *D'Orb.*
gracilis, *Macgil.*
bellis, *Macgil.*
fruticosa, *Macgil.*

Polyzoa from Port Phillip Heads, Victoria. Dredged by J. Bracebridge Wilson.[1]

—	—	P. Phill. Heads	—
	ENTOPROCTA		
	Pedicellinopsis, *Hincks*		
	fruticosa, *Hincks*	*	
	CTENOSTOMATA, *Busk*		
	Flustrella, *Gray*		
	hispida, *Fabric.*	*	
	form. cylindrica, *Hincks*	*	
	dichotoma, *V. Sahr.*	*	{ = Verrucularia, id. *V. Sahr.* ? = Farciminaria, id. *Busk*
	CHEILOSTOMATA, *Busk*		
7	Catenicella, *Blainv.*		
	amphora, *Busk*	*	
	concinna, *Macgil.*	*	
	Wilsoni, *Macgil.*	*	
12	Scrupocellaria, *Van Ben.*		
	obtecta, *Haswell*	*	
31	Diachoris, *Busk*		
	crotali, *Busk*	*	

[1] See 'Ann. Mag. Nat. Hist.,' August 1882 and 1884; and 'Descrip. of New Polyzoa,' Macgil., Roy. Soc. Vict., 1880–1883.

This list is far from being complete, but it is compiled from published species (Macgil. and Hincks), and from a list sent with a series of specimens from Port Phillip Heads by Miss E. C. Jelly—some of the dredgings of Mr. Bracebridge Wilson.

Polyzoa from Port Phillip Heads, Victoria—continued.

—	—	P. Phill. Heads	—
	CHEILOSTOMATA—*cont.*		
32	Membranipora, *Blainv.*		
	permunita, *Hincks*	*	
	pyrula, *Hincks*	*	
	radicifera, *Hincks*	*	
34	Biflustra, *D'Orb.*		
	perfragilis, *Macgil.*	*	
41	Caleschara, *Macgil.*		
	denticulata, *Macgil.*	*	
47	Cellaria		
	fistulosa	*	
	var. australis	*	
	rigida, *Macgil.*	*	
	Porina		
	magnirostris, *Macgil.*	*	
	gracilis, *Lamx.*	*	Escharina, Challenger
	Petralia, *Macgil.*		See genus of Retepo-ridæ, *Busk*
	undata, *Macgil.*	*	
60	Cribrilina, *Gray*		
	monoceros, *Macgil.*	*	
65	Lepralia, *Johnst.*		
	striatula, *Smitt*	*	
67	Porella, *Gray*		
	marsupium, *Macgil.*	*	
	rostrata, *Hincks*	*	
	CYCLICOPORIDÆ, *Hincks*		
	Cyclicopora, *Hincks*		=Lepralia, *Macgil.*
	longipora, *Macgil.* sp.	*	=Cyclicopora prælonga, *Hincks*
70	Mucronella, *Hincks*		
	tricuspis, *Hincks*	*	
72	Schizoporella, *Hincks*		
	accuminata, *Hincks*	*	
	conservata, *Waters*	*	
	latisinuata, *Hincks*	*	
80	Adeona, *Lamx.*		
	sp.	*	
	Dictyopora, *Macgil.*		
	Wilsoni, *Macgil.*	*	
	albida, *Kirchin*	*?	Adeone
	var. avicularis, *Macgil.*	*	
	Lekythopora, *Macgil.*		
	hystrix, *Macgil.*	*	
	CYCLOSTOMATA, *Busk*		
	Lichenopora		
	reticulata, *Macgil.*	*	Discoporella, id.
	pristis, *Macgil.*	*	" "
	echinata, *Macgil.*	*	" "
	Hornera, *Lamx.*		Retihornera, *Busk*
	foliacea, *Macgil.*	*	
	Fasciculipora		
	bellis, *Macgil.*	*	
	fruticosa, *Macgil.*	*	

Polyzoa from Bass's Straits. Rev. T. Hincks.

—	—	British	Bass's Straits	Arctic	Mediterranean	—
	Fam. **Eucratiidæ**					
2	Eucratea, *Lamx.*					
	chelata, *Linn.*	4	*			
24	Dimetopia, *Busk*					
	cornuta, *Busk*		*			
	Fam. **Catenicellidæ**					
7	Catenicella, *De Blainv.*					
	ventricosa, *Busk*		*			
	plagiostoma, *Busk*					
	a setigera, *Macgil.*		*			
	cornuta, *Busk*		*			
	Wilsoni ? *Macgil.*		*			
	unbonata, *Busk*		*			
	sp.		*			
	Calpidium, *Busk*					
	ornatum, *Busk*		*			
	Fam. **Cellulariidæ**					
9	Cellularia, *Pallas*					
	cuspidata, *Busk*		*			
12	Scrupocellaria, *Van Ben.*					
	ornithorhynchus ? *W. T.*		*			
15	Cuberea, *Lamx.*					
	rudis, *Busk*		*			
	grandis, *Hincks*		*			
13	Canda, *Lamx.*					
	arachnoides, *Lamx.*		*			
	Fam. **Bicellariidæ**					
16	Bicellaria, *De Blainv.*					
	grandis, *Busk*		*			
31	Diachoris, *Busk*					
	crotali, *Busk*		*			Rare ?
	spinigera, *Macgil.*		*			Rare ?
	Fam. **Cellelariidæ**					
47	Cellaria, *Lamx.* (pt.)					
	fistulosa, *Linn.*	36	* ?			
	a australis, *Macgil.*		*			Common
	tenuirostris, *Busk*		*			Common
	Fam. **Flustridæ**					
29	Flustra, *Linn.*					
	dissimilis, *Busk*					
	Fam. **Membraniporidæ**					
32	Membranipora, *De Blainv.*					
	lineata, *Linn.*	55	*	*	*	
	inarmuta, *Hincks*		*			
	cervicornis, *Busk*		*			Common
	Savartii, *Aud.*		*		*	
	pyrula, *Hincks* = lineata, *Macgil.*		*			

Polyzoa from Bass's Straits—continued.

—	—	British	Bass's Straits	Arctic	Mediterranean	—
	Fam. **Membraniporidæ**—*cont.*					
	Membranipora					
	vitrea, *Hincks*		*			
	radicifera, *Hincks*		*			
	permuta, *Hincks*		*			
	trifolium, *Macgil.* = Lepralia, *id.*		*			
	denticulata, *Macgil.* = Caleschara, *id.*		*			
	punctigera, *Hincks*		*			
	inornata, *Hincks*		*			
	? roborata, *Hincks*		*			
	Fam. **Microporidæ**					
38	Micropora, *Gray*					
	coriacea, *Esper, var.*	74	*			
40	Steganoporella, *Smitt*					
	magnilabris, *Busk*		*			
	Fam. **Cribrilinidæ**					
60	Cribrilina, *Gray*					
	radiata, *Moll.*	78	*			
	ferox, *Macgil.*		*			
	tubulifera, *Hincks*		*			
	speciosa, *Hincks*		*			
	? monoceros, *Macgil.*		*			
	? = punctata		*			
	Fam. **Microporellidæ**, *Hincks*					
63	Microporella, *Hincks*					
	ciliata, *Pallas*	90	*			
	var.					
	Malusii, *Aud.*	92	*			
	diadema, *Macgil.*		*			
	var.					
	mucronata, *Macgil.* = Eschara, *id.*		*			
	Monoporella, *Hincks*					
	nodulifera, *Hincks*		*			
	lepida, *Hincks*		*			
	Fam. **Porinidæ**					
	Porina, *D'Orbigny*					
	gracilis, *Lamx.*		*			
	Fam. **Myriozoidæ** (pt.), *Smitt*					
	Schizoporella, *Hincks*					
	Cecilii, *Aud.*	132	*			
	= Lep. crystallina, *Macgil.*		*			
	biaperta, *Mich.*	121	*			
	= L. megasoma, *Macgil.*		*			
	circinata, *Macgil.*		*			

Polyzoa from Bass's Straits—continued.

—	—	British	Bass's Straits	Arctic	Mediterranean	—
	Fam. **Myriozoidæ**—*cont.*					
	Schizoporella					
	obliqua, *Macgil.* = Eschara, *id.*		*			
	triangula, *Hincks*		*			
	tumida, *Hincks*		*			
	acuminata, *Hincks*		*			
3	Hippothoa, *Lamx.*					
	divaricata, *Lamx.*	145	*			
	distans, *Macgil.* = H. flagellum, *May*	150	*			
	Fam. **Escharidæ**, *Smitt* (pt.)					
65	Lepralia, *Johnst.* (pt.)					
	cleidostoma, *Smitt*		*			
	var.		*			
	Poissonii, *Aud.*		*			
67	Porella, *Gray*					
	concinna, *Busk*	163	*			
	marsupium, *Macgil.*		*			
69	Smittia, *Hincks*					
	Landsborovii, *Johnst.*	172	*			
	α purpurea, *Hincks*		*			
	trispinosa, *Johnst.*	180	*			
	reticulata, *Macgil.*		*			
	var.		*			
70	Mucronella, *Hincks*					
	spinosissima, *Hincks*		*			
	teres, *Hincks* = allied to M. ventricosa		*			
	tricuspis, *Hincks*		*			
	Rhynchopora, *Hincks*					
	longirostris, *Hincks*		*			
	bispinosa, *Johnst.*	202	*			
57	Retepora, *Imp.*					
	monilifera, *Macgil.*		*			
	robusta, *Hincks*		*			
	granulata, *Macgil.*		*			
	Fam. **Celleporidæ**					
83	Cellepora, *Fabr.*					
	albirostris, *Smitt*		*			
	lævis, *Haswell*		*			
	mammillata, *Bk.*		*			
	granum, *Bk.*		*			
	Fam. **Selenariidæ**, *Bk.*					
85	Lunultes, *Bk.*		*			
	incisa, *Hincks*		*			
	Fam. **Cyclostomata**					
	Hornera, *Lamouroux*					
	foliacea, *Macgil.* = Retihornera		*			
	Lichenopora, *Defrance*		*			
	hispida, *Flem.*	249	*			

D.—*Australian Region. Lat.* 42° 42′ *South, long.* 134° 10′ *East.*

Genera in Report	Bathymetrical Distribution	2600, 1450–1425 fath.	825 to 520 fath.	150 fath.	49–35, 33 fath.	28 to 18 fath.	Admiralty Is.	8 fath.	—
83	Cellepora solida . . .	*							
	hastigera . . .				*				
	pustulata . . .			*					C.
	columnaris . . .				*				
	bidenticulata . .				*				
	var. subequalis .				*				
	tuberculata . . .				*				
	apiculata . . .				*				
	Jacksoniensis . .				*				
	bilabiata . . .				*				
	discoidea . . .							*	
	tridenticulata . .							*	
	guineensis . . .							*	
47	Salicornaria Malvinensis .	*							B. C. G.
	divaricata . . .			*					
	bicornis . . .			*					
	clavata . . .				*				C. G.
	simplex . . .				*				
	gracilis . . .							*	
57	Retepora Margaritacea .	*							
	columnifera . .				*				
	crassa				*				
	delicatula . . .				*				
	Phœnicea . . .				*				
	victoriensis . . .				*				
	apiculata . . .					*			
	producta . . .					*			E.
	Jacksoniensis (2 to 10 fath.) . . .								
	hirsuta . . .							*	
	tubulata . . .							*	
	simplex . . .						*		
9	Cellularia cirrata . .	*							
	cuspidata . . .				*				
28	Farciminaria hexagona .	*	*						C.
26	Brettia australis . .		*						
16	Bicellaria bella . .		*						
	moluccensis . .		*						
	macilenta . . .		*						
29	Flustra biseriata . .		*						G.
	denticulata . . .			*					
	membraniporides .				*				
30	Carbasea dissimilis . .		*		*				
	Moseleyi . . .		*						
	cribriformis . .				*	*		*	
	elegans . . .				*				B.
	pisciformis . . .				*				
45	Bifaxaria papillata . .		*						
50	Siphonicytara serrulata .		*						
15	Caberea rostrata . .			*					
	lata				*			*	
	rudis				*				

D.—*Australian Region*—continued.

Genera in Report	Bathymetrical Distribution	2600, 1450–1425 fath.	825 to 520 fath.	150 fath.	49–35, 33 fath.	28 to 18 fath.	Admiralty Is.	8 fath.	—
72	Schizoporella marsupifera			*					C.
	Jacksonensis . .				*				
	triangula . . .				*				C.
	Cecilii . . .				*				
2	Eucratea chelata . .			*					
7	Catenicella ventricosa .			*					
	hastata . . .			*	*				
	plagiostoma . .			*	*				
	elegans . . .			*					
	umbonata . . .				*				
	pulchella . . .				*				
	cribraria . . .				*				
23	Didymia simplex . .			*					
24	Dimetopia cornuta . .			*					
32	Membranipora spinosa .			*					
	crassimarginata . .								
	var. erecta . .				*				C.
	albida					*			
33	Amphiblestrum umbonatum			*					
	Amphiblestrum cervicorne				*				
46	Calymmophora lucida .			*					
49	Tubucellaria hirsuta .			*					
69	Smittia transversa . .			*					
80	Adeona appendiculata .			*					
81	Adeonella intricaria . .				*				
	pectinata . . .							*	
14	Nellia oculata . . .				*	*			B. C. E.
64	Eschara gracilis . .				* *				
70	Mucronella bisinuata .				*				
	pyriformis . . .				*				
	simplicissima . .				*				
	quadrata . . .					*			
75	Haswellia australiensis .				*			*	
1	Ætea anguina . . .				*				A. C. G.
31	Diachoris crotali . .				*				
	Magellanica . .							*	
35	Foveolaria elliptica . .				*				B.
41	Caleschara denticulata .								
	var. tenuis . .				*				
60	Cribrilina monoceros .				*				B. C. F. G.
65	Lepralia tuberosa . .				*				
	celleporoides . .							*	
	lonchæa . . .						*		
	dorsiporosa . . .							*	
11	Emma crystallina . .				*				
85	Lunularia capulus . .				*				
12	Scrupocellaria ciliata .					*			
	securifera . . .						*		
6	Chlidonia cordieri . .							*	
68	Escharoides occlusa . .							*	C. E.
84	Cupularia guineensis .							*	

C.—*South Indian or Kerguelen Region. Lat.* 62° 26′ *South, long.* 95° 44′ *East.*

Genera in Report	Bathymetrical Distribution	1975 to 1950 fath.	1675 to 1600 fath.	210 fath.	150 to 140 fath.	Prince Edw. Isl. 80 to 1500 fath.	75 to 69 fath.	20 fath.	—
16	Bicellaria infundibulata	*	*						
	pectogemma				* *		*		
17	Bugula bicornis	*							
	reticulata		*						
	sinuosa					*			
	longissima						*	*	
47	Salicornaria magnifica	*							A. B.
	clavata					*	*	*	D. G.
	Malvinensis						*	*	B. D. G.
	variabilis							*	B. G.
55	Onchopora Sinclairii	*			*			*	
28	Farciminaria magna		*						B.
	hexagona				*				
35	Foveolaria orbicularis		*						
14	Nellia oculata			*			*		B. D. E.
15	Caberea Darwinii			*		*	*	*	B.
57	Retepora gigantea			*					
	cavernosa			*					
58	Reteporella myriozoides			*					
	flabellata						*		
68	Escharoides occlusa			*					D. E.
	verruculata						*		
69	Smittia graciosa			*					
	Marionensis					*		*	
	Jacobensis						*		A.
70	Mucronella ventricosa								
	var. multispinata			*		*			
	rostrigera					*			
	tricuspis					*			B.
74	Myriozoum Marionense			*		*	* *		
83	Cellepora vagans			*					
	mamillata								
	var. atlantica			*					B.
	bicornis				*	*	*		B.
	albirostris						*		
	pustulata						*		D.
	Eatonensis							*	B. G.
72	Schizoporella elegans			*					B.
	triangula						*		D.
	marsupifera						*		D.
32	Membranipora galeata							*	
	var. furcata				*		*		
	crassimarginata								
	var. erecta						*		D.
30	Carbasea ovoidea					*	*	*	B. G.
39	Vincularia gothica					*			
	var. granulata						*		
44	Electra cylindracea					*			
3	Hippothoa flagellum						*		
8	Catenaria attenuata						*		
9	Cellularia quadrata						*		
	elongata							*	

C.—*South Indian or Kerguelen Region*—continued.

Genera in Report	Bathymetrical Distribution	1975 to 1950 fath.	1675 to 1600 fath.	210 fath.	150 to 140 fath.	Prince Edw. Isl. 80 to 1500 fath.	75 to 69 fath.	20 fath.	—
31	Diachoris Magellanica .								
	var. distans . .						*		
	inermis . . .							*	
60	Cribrilina philomela .						*		
	var. adnata . .						* *		
	monoceros . . .						*		B. D. F. G.
62	Flustramorpha marginata						*		B.
10	Menipea benemunita .							*	B. G.
	flagellifera . . .						*	*	B.
	Marionensis . .						*		
33	Amphiblestrum cristatum							*	
66	Chorizopora hyalina .								
	var. Bougainvillei .							*	B.

Polyzoa from India, Coast of Burmah, Rev. T. Hincks.

—	—	British	India	Atlantic	—
	Fam. **Cellulariidæ**				
12	Scrupocellaria. *Van Ben.*				
	diadema, *Busk* . .		*		Queensland
	Fam. **Bicellariidæ**				
20	Beania, *Johnst.*				
	mirabilis, *Johnst.* . .	34	*	*	Scandinavia, Medit.
	Fam. **Membraniporidæ**				
32	Membranipora, *Blainv.*				
	favus, *Hincks* . . .		*		
	marginella, *Hks.* . .		*		
	Fam. **Steganoporellidæ**, *Hks.* (May 1884.)				
43	Steganoporella, *Smitt*				
	magnilabris, *Busk* . .		*	*	Bass's Straits
	Smittipora, *J. Jullien* ('Am. Nat. Hist.' May 1884)				
	abyssicola, *Smitt* = Setosella, *Hks.*		*		Florida, Singapore
	Fam. **Microporellidæ**				
63	Microporella, *Hincks*				
	violacea, *Johnst.* (see *Busk*)	99			
	a plagiopora, *Busk* .		*		Cor. Crag, Italian Pliocene
	fuegensis, *Busk* . .		*		Tierra del Fuego

Polyzoa from India, Coast of Burmah—continued.

—	—	British	India	Atlantic	—
	Fam. **Myriozoidæ** (pt. *Smitt*)				
72	Schizoporella, *Hincks* biaperta, *Mich.*	121	*		
	Fam. **Escharidæ** (pt. *Smitt*)				
65	Lepralia, *Johnst.* robusta, *Hincks*		*		
67	Porella, *Gray* malleolus, *Hks.*		*		
69	Smittia, *Hincks* trispinosa, *Johnst.* var.	180	*		Norway, Arctic, Medit.
	Fam. **Celleporidæ**				
83	Cellepora ? sp. ? brunnea, *Hincks*		*		

E.—*Philippine or Japanese Region. From* 110° *E. to* 160° *West and North.*

—	—	2,300 fathoms } Station 241	500 fathoms } Station 214	82 fathoms } Station 201	8 to 50 fathoms } Cobie	18 fathoms } Station 208	10 fathoms } Station 212	10 fathoms } Sambo-angan	—
28	Farciminaria pacifica	*							
45	Bifaxaria lævis		*						
81	Adeonella platalea			*					
	polymorpha							*	
57	Retepora victoriensis var. japonica				*				
	producta							*	D.
	simplex							*	D.
	mucronata					*			
	philippinensis						*		
65	Lepralia japonica				*				
	feegeensis					*			
14	Nellia oculata					*			B. C. D.
33	Amphiblestrum papillatum					*			
63	Microporella personata					*			
34	Biflustra Savartii							*	
68	Escharoides occlusa							*	C. D.
83	Cellepora samboangensis							*	

G.—*South Pacific Region. From* 160° *to* 70° *West.*

—	—	Station 299 2160	Station 280 1940	Station 303 1325	Station 304 45	Station 312 9	—
10	Menipea pateriformis	*					
	benemunita			*			B. C.
	aculeata			*			B.
16	Bugula reticulata	*					B. C.
18	Kinetoskias pocillum	*					B.
29	Flustra biseriata	*					D.
8	Catenaria bicornis		*				
30	Carbasea ovoidea			*		*	B. C.
60	Cribrilina monoceros			*			B. C. D. F.
83	Cellepora Eatonensis			*			B. C.
	signata			*			
1	Aetea anguina				*		A. C. D.
47	Salicornaria clavata				*		C. D.
	variabilis				*		B. C.
	Malvinensis				*		B. C. D.
72	Schizoporella longispinata . .					*	

F.—*North Pacific Region. From* 160 *W. to West Coast of North America.*

—	—	Station 253 3,035	Honoruru, Sandwich Islands 20 to 40 fathoms	—
45	Bifaxaria abyssicola	*		
60	Cribrilina monoceros . . .	*		B. C. D. G.
17	Bugula Johnstoniæ	*		Not in the text. Too
78*	Phylactella, sp. (?)	*		fragmentary for com-
12	Scrupocellaria ornithorhynchus		*	plete identification.
40	Steganoporella magnilabris .		*	
57	Retepora denticulata . .		*	
	contortuplicata . . .		*	
66	Chorizopora honolulensis . .		*	
69	Smittia marsupialis . . .		*	
70	Mucronella delicatula . .		*	
	magnifica		*	
72	Schizoporella furcata . .		*	
	tenuis		*	
74	Myriozoum honolulensæ . .		*	
83	Cellepora honolulensis . .		*	
	polymorpha		*	
	vagans		*	C.

Pt. I.—*Polyzoa of the Queen Charlotte Islands*, Rev. Thos. Hincks, *North Pacific*.

—	—	British	Queen Charlotte Islands	Straits of Magellan	California	Mediterranean	Arctic	—
	Fam. **Æteidæ**							
1	Ætea, *Lamx.*							
	ligulata, *Busk* . .		*	*				
	Fam. **Eucratiidæ**							
22	Gemellaria, *Savig.*							
	loricata, *Linn.* . .	7	*					
	Fam. **Cellularidæ**							
10	Menipea, *Lamx.*							
	ternata, *Ell.* and *Sol.* .	13	*				*	
	compacta, *Hincks* .		*					
	a triplex, *Hincks* .		*					
12	Scrupocellaria, *Van Ben.*							
	varians, *Hincks* . .		*					
	brevisetis, *Hincks* .		*					
15	Caberea, *Lamx.*							
	Ellisii, *Fleming* . .	20	*				*	
	Fam. **Bicellariidæ**							
17	Bugula, *Oken*							
	avicularia, *Linn.* . .	24	*			*	*	
	Murrayana, *Johnst.* .	32	*				*	
	Fam. **Cellariidæ**							
47	Cellaria, *Lamx.*							
	borealis, *Busk* . .		*				*	
	mandibulata, *Hincks* .		*					
	Fam. **Membraniporidæ**							
	(Group A. Flustridæ, *Hks.*)							
29	Flustra, *Linn.*							
	membranaceo-truncata, *Sm.*		*				*	
32	Membranipora, *De Blainv.*							
	(Group B.)							
	unicornis, *Flem.* . .	61	*				*	
	Rossellii, *Aud.* . .	68	*		*	*		
	tenuirostris, *Hincks* .		*		*	*		
	horrida, *Hincks* . .		*		*			
	patula, *Hincks* . .		*		*			
	variegata, *Hincks* .		*		*			
	acifera, *Mcgil.* . .		*					
	a multispinata, *Hks.*		*					
	echinus, *Hincks* . .		*					
	exilis, *Hincks* . .		*					

Pt. I.—*Polyzoa of the Queen Charlotte Islands*—continued.

—	—	British	Queen Charlotte Islands	Straits of Magellan	California	Mediterranean	Arctic	—
	Membraniporidæ—*cont.*							
	Membranipora							
	Sophiæ, *Busk*		*				*	
	α matura, *Hincks*		*					= M. conferta, 'Annals,' 1882
	nigrans, *Hincks*		*					
	levata, *Hincks*		*					
	protecta, *Hincks*		*					See *H.* for allied forms, p. 10
	corniculifera, *Hincks*		*					
	minuscula, *Hincks*		*					
	membranacea, *Linn.*	53	*				*	
	α serrata, *Hincks*		*					
	velata, *Hincks*		*					
	pallida, *Hincks*		*					See Report, p. 39
	Fam. **Microporidæ**							
38	Micropora coriacea, *Esp.* var.	74	*					
	Fam. **Cribrilinidæ**							
60	Cribrilina, *Gray*							
	furcata, *Hincks*		*					
	hippocrepis, *Hincks*		*					
	radiata, *Moll.*	78	*			*		
	Fam. **Microporellidæ**							
63	Microporella, *Hincks*							
	ciliata, *Pallas*	90	*			*		
	α vibraculifera, *Hks.*		*		*			
	β umbonata, *Hincks*		*					
	Malusii	92	*			*		
	Monoporella, *Hincks*							
	brunnea, *Hincks*		*					
	Fam. **Porinidæ**							
	Lagenipora, *Hincks*							
	spinulosa, *Hincks*	*						
	Fam. **Myriozoidæ** (pt.), *Smitt*							
72	Schizoporella, *Hincks*							
	auriculata, *Hassall*	125	*					
	α ochracea, *Hincks*	126	*					
	Cecilii, *Aud.*	132	*			*		
	hyalina, *Linn.*	134	*		*		*	
	sanguinea, *Norman*	119	*			*		
	biaperta, *Michelin*	121	*			*	*	
	sinuosa, *Busk*	130	*				*	
	crassilabris, *Hincks*		*					
	crassirostris, *Hincks*		*					
	longirostrata, *Hincks*		*					

Pt. I.—*Polyzoa of the Queen Charlotte Islands*—continued.

—	—	British	Queen Charlotte Islands	Straits of Magellan	California	Mediterranean	Arctic	—
	Fam. **Myriozoidæ**—*cont.*							
	Schizoporella							
	insculpta, *Hincks* .		*					
	tumulosa, *Hincks* .		*					
	pristina, *Hincks* . .		*					
	maculosa, *Hincks* .		*					
	Dawsoni, *Hincks* . .		*					
	cruenta, *Norman* . .	133	*					
	torquata, *D'Orb.* and *Lamx*		*					
	linearis, *Hassall* . .	114	*					
	a inarmata . .		*					
	Schizotheca, *Hincks*							
	fissurella, *Hincks* .		*					= Schizoporella, 'Annals,' 1882
3	Hippothoa, *Lamx.*							
	expansa, *Dawson* .	149	*					
	distans, *Macgil.* .	* H.	*			*		
74	Myriozoum, *Donati*						*	
	coarctatum, *Sars* .		*				*	
	Fam. **Escharidæ** (pt.) *Smitt*							
65	Lepralia (pt.), *Johnst.*							
	nitescens, *Hincks* .		*					
	bilabiata, *Hincks* .		*					
	claviculata, *Hincks* .		*					
	cleidostoma, *Smitt* (var.) . . .		*					
67	Porella, *Gray*							
	concinna, *Busk* . .	163	*				*	
	marsupium, *Macgil.* .		*					
	a porifera, *Hincks* .		*					
	major, *Hincks* . .		*					
	? argentia, *Hincks* .		*					
69	Smittia, *Hincks*							
	trispinosa, *Johnst.* .	180	*				*	
	plicata, *Smitt* . .		*				*	
	spathulifera, *Hincks* .		*					
70	Mucronella, *Hincks*							
	ventricosa, *Hassall* .	188	*			*	*	
	pavonella, *Alder* .	195	*				*	
	prælucida, *Hincks* .		*					
	prælonga, *Hincks* .		*					
	spinosissima, *Hincks* .		*					
	a major, *Hincks* .		*					
57	Retepora, *Imp.*							
	Wallichiana, *Hincks* .		*					
	Fam. **Celleporidæ**							
83	Cellepora, *Fabr.*		*				*	
	incrassata, *Lamk.* .		*					
	? sp.		*					

Pt. II.—*Polyzoa Queen Charlotte Islands*, Hincks.

—	British	Queen Charlotte Islands
CYCLOSTOMATA		
Crisia cornuta, *Linn.*	216	*
eburnea, *Linn.*	218	*
denticulata, *Lamk.*	221	*
Stomatopora major, *Johnst.*	223	*
diastoporides, *Nor.*	229	*
incrassata	231	*
Tubulipora, lobulata, *Hass.*	235	*
perfragilis, *Hincks*		*
Dawsoni, *Hincks*		*
fasciculifera, *Hincks*		*
Diastopora patina, *Lamk.*	243	*
Sarniensis, *Nor.*	245	*
suborbicularis, *Hincks*	245	*
Lichenopora hispida, *Flem.*	249	*
verrucaria, *Fabr.*	253	*

ADDENDA.

Cyclostomatous Bryozoa (*Polyzoa*) *from Australia.* A. W. Waters, F.G.S., '*Quart. Jour. Geol. Soc.*,' *Vol. XL.* (*November* 1884).

After the publication of my fifth British Association Report on Fossil Polyzoa, 1884, the above paper was published in the 'Journal of the Geological Society.' I was able, however, to refer to the reading, &c. in a note when correcting the proof sheets of the Report; but as I consider the paper a very important one, I make no apology for giving the following rather full digest, together with remarks on some of the species. Mr. Waters describes thirty-four species of Cyclostomata from Australia, some of which are new, but as he reintroduces for our consideration some of the—now obsolete—names of D'Orbigny and others, it may be well to give the full list of synonyms, &c., furnished by the author.

As a preface to the descriptive matter of this paper, Mr. Waters reviews the whole of the work on Fossil Cyclostomata—very briefly, however—of previous authors; and as some of his remarks bear upon the classification of the Cyclostomata, the student of both Fossil and Recent forms should master the special details of some of the zoœcial characters of the group, especially those parts which refer to the size of the tubes, the ovicells, and also of the pores of the interspaces—cancelli. These details may ultimately help us to understand, more fully than we at present understand, the apparently homologous characters in Palæozoic, and in some few Mesozoic, species of Polyzoa.

1. Crisia unipora, *D'Orb.*, *op. cit.* p. 683, pl. xxx. fig. 1
   = Idmonea unipora, *D'Orb.*, 'Pal. Fr.'
   = Crisina unipora, *D'Orb.*, 'Prodr.' p. 265
   = Crisina elegans, *D'Orb.*, 'Pal. Fr.' pl. (only) 613.

I should be rather inclined to place this species in the genus *Filisparsa*, than in *Crisia*, but as Mr. Waters founds his opinion upon the classifi-

catory position of the species upon the 'closure' of the tube, it would be mere folly to shift it merely because the shape of the zoarium differs from the ordinary run of Crisia.

Locality: Curdie's Creek, Australia.

2. Idmonea atlantica, *Forbes*, *op. cit.* p. 683
   = Idmonea radians, *Van Ben.* (non *Lamk.*)
   = Idmonea inconstans, *Stol.*, 'Bry. Orak. Bay.'
   Localities: Orakei Bay (*Stol.*); Curdie's Creek; Mount Gambier; Bairnsdale.
3. „ Milneana, *D'Orb.*, *op. cit.* p. 648.
   Id., 'Voy. dans l'Amér. Mérid.' vol. v. *D'Orb.*
   = Idmonea giebeli, *Stol.* (Orak. Bay)
   = Idmonea giebeliana, *Stol.* (Orak. Bay)
   = Idmonea notomale, *Busk*, 'Cat. Mar. Pol.'
   Localities: Orakei Bay; Mount Gambier; Curdie's Creek; Bairnsdale.
4. „ radians, *Lamk.*, *op. cit.* p. 684
   = Retepora radians, *Lamk.*, 'Anim. sans vert.,' ii. p. 183
   = Idmonea radians, *Stol.*, 'Bry. d. Orak. Bay.'
   Locality: Mount Gambier.
5. „ Hockstetteriana, *Stol.*, *op. cit.* p. 684, pl. xxx. figs. 12, 13
   = Crisina, *id.*, *Stol.*, 'Foss. Bry. der Orak. Bay.'
   Localities: Orakei Bay; Curdie's Creek.
6. „ bifrons, *Waters*, *op. cit.* p. 685, pl. xxx. figs. 10, 11
   =(?)Tubigera disticha, *D'Orb.*, 'Pal. France'
   =(?)Idmonea disticha, *Hag.*
   Locality: Aldinga.
7. „ aldingensis, *Waters*, *op. cit.* Addendum, p. 696.
   Locality: Aldinga.

'The appearance is much the same as that of *Clavitubigera convexa* (*D'Orb.*, 'Pal. Fr.' pl. 746, figs. 12–15), with the exception that the dorsal surface is concave.'—*A. Waters.*

8. Entalophora verticillata, *Goldf.*, *op. cit.* p. 658
   = Ceriopora verticillata, *Goldf.*, 'Petrifac.'
   = Spiropora antiqua, *D'Orb.*, 'Pal. Fr.'
   = Spiropora neocomiensis, *D'Orb.*, 'Pal. Fr.' p. 708, pl. 784, figs. 1, 2
   = Spiropora verticillata, *Novak.*
   = Spiropora calamus, *Gabb & Horn.*
   =(?)Mitoclema cinctosa, *Ulrich*, 'Amer. Pal. Bry. Jour. Cincin. Soc.' v. p. 159, pl. vi. figs. 7, 7*a*.

Ulrich's *Mitoclema cinctosa* is undoubtedly an Entalophora, but I am very doubtful about its being in any sense identical with any of the other forms cited above by Mr. Waters. The Trenton species are related to the Upper Silurian species of 'Spiropora' described by me in the 'Quart. Jour. Geol. Soc.' p. 55, Feb. 1882; but when describing these forms, I was unable to identify any of the Palæozoic with Jurassic or Cretaceous forms. I have allowed Mr. Waters's suggestion to stand as above, but have simply placed (?) before it.

Other synonyms will be found in Novak and D'Orbigny.

Locality: Mount Gambier.

9. Entalophora raripora, *D'Orb.*, *op. cit.* p. 686
= Pustulopora virgula, *Hag.*
= Entalophora icauensis, *D'Orb*
= „ attenuata, *Stol.*
= „ anomale, *Manzoni*
= „ Haastiana, *Stol.*
= Pustulopora proboscidea, *Busk.*

In justifying the above synonymy Mr. A. W. Waters says: 'I have prepared sections of recent specimens, and also some from the Chalk, Miocene, and Pliocene, without being able to find any difference. The aperture is about 0·16 mm. in diameter.'

Localities: Orak. Bay; Curdie's Creek; Muddy Creek; Mt. Gambier; Aldinga.

10. Entalophora neocomiensis, *D'Orb.*, *op. cit.* p. 686, 'Pal. Fr.' p. 782, pl. 616, figs. 15–18.
? Bidiastopora, *id.*, *D'Orb.* 'Pal. Fr.' p. 800, pl. 784, figs. 9–11
= Cricopora pulchella, *Reuss*
= Spiropora pulchella, *Reuss*
= Pustulopora pulchella, *Manzoni*
= Bidiastopora Toetoeana, *Stol.*

Localities: Orakei Bay; Curdie's Creek; Mt. Gambier; Muddy Creek.

11. Filisparsa orakeinsis, *Stol.*, *op. cit.* p. 687.
Stoliczka, 'Foss. Bry. der Orakei Bay,' pl. xviii. figs. 1, 2.

Localities: Orakei Bay; Curdie's Creek; Mt. Gambier.

Mr. Waters, I think, is quite justified in restoring this genus for certain fossil species. Dr. Jullien (Dragages d. Trav. Bryozoaises, 'Bull. Soc. Zool. de France,' tome vii. 1882, p. 500) 'proposes to make a new genus, *Tervia*, for *Filisparsa*, D'Orb.; but I do not see what reason there can be for this change of name' (*A. W. W.*).

12. Hornera frondiculata, *Lamx.*, *op. cit.* p. 687
= Hornera porosa, *Stol.*

Localities: Curdie's Creek; river Murray cliffs, Bairnsdale; Mt. Gambier. Living: Mediterranean.

13. „ foliacea, *Macgil.*, *op. cit.* p. 688, pl. xxx. fig. 18
= Retihornera foliacea, *Busk*, 'Cat.' pt. iii.

Localities: Living: Portland Bay; Wilson's Promontory; Tasmania. Fossil: Bairnsdale; Mt. Gambier; river Murray cliffs.

14. Stomatopora granulata, *M.-Ed.* *Var.* minor.

Locality: Waurn Ponds.

15. Diastopora suborbicularis, *Hincks*, *op. cit.* p. 689.

Locality: Waurn Ponds.

16. „ patina, *Lamk.*, *op. cit.* p. 689.

Locality: Mt. Gambier.

17. Reticulipora, sp. (*op. cit.* p. 689).
Locality : Mt. Gambier.
18. „ transennata, *Waters, op. cit.* p. 689, pl. xxx. figs. 2. 3, 6, 7.
Locality : Aldinga.
19. Discotubigera clypeata, *Lamx., op. cit.* p. 690, pl. xxxi. figs. 15, 16, 19
= Pelagia clypeata, *Michelin*
= Apseudesia clypeata, *Haime.*
Localities : Aldinga ; Curdie's Creek.
20. „ iterata, *Waters,* p. 690, pl. xxxi. figs. 14, 17.
Locality : Aldinga.
21. Pavotubigera flabellata, *D'Orb.,* 'Pal. Fr.' pl. 752, figs. 4–8
= (?) Semitubigera lamellosa, *D'Orb.,* 'Pal. Fr.' pl. 750, figs. 16–18.
Locality : Aldinga.
22. „ dimidiata, *Reuss, op. cit.* p. 691, pl. xxxi. fig. 25
= Defrancia, *id., Reuss.*

On this species Mr. Waters makes some admirable remarks, to which the student should refer.

Locality : Mt. Gambier.

23. „ gambierensis, *Waters,* p. 692, pl. xxx. fig. 9.
24. Defrancia exaltata, *Waters,* p. 692, pl. xxxi. fig. 23. Probably related to Defrancia diadema, *Goldf., Hag.,* and *D'Orb.*
Locality : Mt. Gambier.
25. Supercytis (?) digitata, *D'Orb.,* p. 692, pl. xxxi. figs. 22, 26, 27. Closely related to Pelagia insignis, *Michelin.*
Locality : Murray cliffs.
26. Fasciculipora sp. (*op. cit.* p. 693).
Locality : Curdie's Creek ; Mt. Gambier.
27. „ conjuncta, *Waters,* p. 693, pl. xxx. figs. 4, 5.
(?) Fasciculipora ramosa, *J. E. Tenison Woods.*
Localities : Mt. Brown Beds (Up. Eocene of Hector), New Zealand ; river Murray cliffs.
28. Lichenopora lispida, *Flem., op. cit.* p. 694. See *Hincks,* 'Brit. Mar. Polyzoa,' p. 473.
Localities : Mt. Gambier ; Bairnsdale ; Muddy Creek, Murray River ; Waurn Ponds.
29. „ radiata, *Aud., op. cit.* p 694.
Localities : Curdie's Creek ; Muddy Creek ; Bairnsdale ; Mt. Gambier ; Napier, New Zealand.
30. „ Aldingensis, *Waters, op. cit.* p. 695.
Locality : Aldinga.
31. „ cochloidea, *D'Orb., op. cit.* p. 695.
= Domopora cochloidea, *D'Orb.,* 'Pal. Fr.'
= Defrancia cochloidea (?) *Hagenow.*
Locality : Mt. Gambier.
32. „ boletiformis, *D'Orb.* (non *Reuss*)
= Tecticavea, *id., D'Orb.,* 'Pal. Fr.' p. 781, figs. 8–12.
Locality : Aldinga.

33. Lichenopora variabilis, *D'Orb.*, *op. cit.* p. 696
= Bimulticavea, *id.*, *D'Orb.*, 'Pal. Fr.'
Locality : Aldinga.

34. Heteropora (sp.), *op. cit.* p. 696.
Locality : Curdie's Creek.

Fossil Cheilostomatous Bryozoa from Aldinga and the river Murray cliffs, South Australia. A. W. WATERS, F.G.S., '*Proceedings of the Geol. Soc.*' No. 467, 1885, p. 57, and 'Quart. Journ. Geol. Soc.' Aug. 1885.

I had already placed in the hands of the printer a digest of the above, compiled from Mr. Waters's paper on the Australian 'Cyclostomata,' &c. and from the 'Abstracts,' &c. of the Geological Society. Mr. Waters's full paper, however, came into my hands while the proofs of the present report were being corrected, and I prefer to give the fuller digest rather than the brief abstract prepared.

The paper is one of the most important issued by the author, and its value as a critical production cannot be lightly estimated. In the body of my report I have stated my views with regard to the details of Mr. Busk's monograph on the 'Challenger' dredgings, and Mr. Waters criticises rather freely the work in question. So far as structural features, in certain species, are concerned, either author is capable of taking care of the opinions expressed, and it is to be hoped that the moot-points raised both by Mr. Busk and by Mr. Waters will be duly considered by specialists before venturing to give undue preference to any classification founded upon mere habit. With regard to the plan adopted in the present report I may be permitted to offer a few remarks, with the new evidence of Mr. Waters before me.

After the issue of Mr. Busk's monograph two courses were open to me—either to adopt his classification, and ignore that of Mr. Hincks, or to adopt that of Mr. Hincks and ignore that of Mr. Busk. In either case I should have had to rearrange the whole of the species differently placed to the plan which I might choose to adopt, thus taking upon myself a responsibility that I had no care to face. The course I have adopted is a medium one, and I do not think that by it I shall raise any undue opposition to the plan of the report. My desire has been, in the compilation of these six reports, to lay before the students of Fossil and Recent Polyzoa as full a digest as possible of work done, altogether irrespective of the mode or plan of the different workers. This free-hand dealing with all manner of investigations has been misunderstood by some few critics, but I do not regret that my labours have been so differently regarded. From Mr. Busk, Mr. Hincks, and from Mr. Waters, I do not fear their adverse but friendly suggestions, for all three know too well the difficulties to be encountered in a work like the present one.

The collection described furnishes 73 species, of which 46 are known living, and 8 are new. This brings up the number of described fossil Australian Polyzoa to 220, of which just about half have been found living. The new species and varieties in this list are marked with an (*) after Mr. Waters's name.

Cellaria malvinensis, *Busk.*	M. Cl.
,, angustiloba, *Busk.*	Ald.
Membranipora circularis, *D'Orb.*	M. Cl.
,, Savartii, *Aud.*	
,, temporaria, *Waters.**	M. Cl.
,, Flemingii, *Busk.*	Ald.
,, parvicella, *T. Woods.*	M. Cl.
,, Michaudiana, *D'Orb.*	Ald.
,, trifolium, *var. Waters.*	Ald.
,, cylindriformis, *Wat.*	M. Cl.[1]
,, radicifera, *Hincks.*	M. Cl.
,, rhynchota, *Busk.*	M. Cl.
,, aperta, *Busk.*	Ald.[2]
Micropora patula, *Wat.*	Ald. and M. Cl.
,, perforata, *Macgil.*	Ald.
Monoporella crassatina, *Wat.*	Ald. and M. Cl.
,, sexangularis, *Goldf*	Ald.
Steganoporella magnilabris, *Busk.*	M. Cl.
,, Rozieri, *Aud.*	
Var. indica, *Hincks.*	M. Cl.
Cribrilina terminata, *Wat.*	M. Cl.
,, figularis, *Johnst.*	M. Cl.
,, radiata, *Moll.*	M. Cl.
Mucronella mucronata, *Smitt.*	M. Cl.
,, nitida, *Verrill.*	Ald. and M. Cl.
,, coccinea.	
Var. mamillata, *Busk.*	Ald.
Var. resupinata, *Manz.*	Ald. and M. Cl.
Microporella grisea, *Lamx.*	
,, coscinopora.	
Var. armata, *Waters.*	M. Cl.
,, violacea, *Johnst.*	
Var. fissa, *Waters.*	
,, symmetrica, *Waters.*	M. Cl.
,, ferrea, *Waters.*	(ferrea.)
,, pocilliformis, *Waters.**	Ald.
,, (Lunulites) magna, *Woods.*	Ald.
,, magnirostris, *Macgil.*	M. Cl.
,, elevata, *Woods.*	Ald. and M. Cl.
Porina coronata, *Reuss.*	Ald. and M. Cl.
Lepralia Burlingtoniensis, *Wat.*	Ald. and M. Cl.
,, edax, *Busk.*	M. Cl.
,, depressa, *var.*	Ald.
,, rostrigera, *Smitt.*	M. Cl.
,, escharella, *Römer.*	Ald.
,, subimmersa, *Macgil.*	Ald.
,, confinita, *Waters.**	Ald.
Smittia Tatei, *Woods.*	Ald. and M. Cl.
,, seriata, *Reuss.*	M. Cl.
,, Landsborovii.	M. Cl.
,, reticulata, *Macgil.*	

[1] *M. Cl.* = Murray Cliffs. [2] *Ald.* = Aldinga.

Smittia Milneana, *Busk.*	
Var. coæquata, *Waters.*	M. Cl.
Schizoporella simplex, *var.*	Ald.
,, vulgaris, *Moll.*	Ald.
,, phymatopora, *Reuss.*	M. Cl.
,, striatula, *Smitt.*	M. Cl.
,, fenestrata, *Wat.*	M. Cl.
,, Cecilii, *Aud.*	M. Cl.
,, protensa, *Waters.**	Ald.
Mastigophora Dutertrei, *Aud.*	M. Cl.
Rhynchopora bispinosa, *Johnst.*	M. Cl.
Retepora marsupiata, *Smitt.*	
Cellepora fossa, *Haswell.*	Ald. and M. Cl.
Var. marsupiata, *Waters.**	M. Cl.
,, coronopus, *Busk.*	Ald.
,, avicularis, *Hincks.*	M. Cl.
,, costata, *Macgil.*	
,, divisa, *Waters.**	
,, mamillata, *Busk.*	M. Cl.
,, albirostris, *Smitt.*	M. Cl.
,, pertusa, *Smitt.*	Ald.
Var. ligulata, *Waters.**	M. Cl.
,, bi-radiata, *Waters.**	M. Cl.
,, tridenticulata, *Busk.*	Ald. and M. Cl.
Lekythopora hystrix, *Macgil.*	M. Cl.
Selenaria maculata, *Busk.*	M. Cl.
Cupularia canariensis, *Busk.*	Ald. and M. Cl.

Fossil Tertiary Polyzoa of the higher Zones, and Note on the Scarcity of Eocene Polyzoa. By ALFRED BELL, Esq.

In my fifth Report on Fossil Polyzoa (1884) I presented a list of species from the Crag and also from the Palæolithic beds of Great Britain. This I did from all the sources that were available to me at the time. Since the publication of my Report in the volumes of the British Association Mr. Alfred Bell, the well-known authority on these upper beds, has compiled for me a complete and corrected list of the distribution of the Polyzoa from every source available to him.

Notes on the Higher Tertiary Zones.

1. Coralline Crag.

2. Lower Red Crag, or Fusus contrarius Zone.—I.e. the oldest part of the Red Crag (Walton-Naze) in which the Fauna is almost entirely free from the mammalia (cetacean and terrestrial), London Clay, and older rocks and fossils and other miscellaneous remains.

3. Middle Red Crag, or F. antiquus Zone.—The district between the rivers Deben and Orwell; with the above remains a large proportion of extinct shells and few living mammalia.

4. Upper Red Crag, including Norwich Crag, free from the above remains. Shells nearly all recent forms; Mammalia, Quaternary, or still living species.

5. Pre-glacial.—I.e. Wexford, Chillesford, Weybourn Sands, Bure Valley, and all beds between the last and the succeeding Arctic or First Glacial period.

6. Arctic.—Bridlington, Tangy Glen, Erie, Errol, Fife, and other beds in and underlying the Boulder Clay.

7. Palæolithic.—Garvel Park, Dalmuir, and most of the Scottish beds in the north; the Lancashire drifts, Selsey, Portrush, and the Cambridgeshire districts; Fauna indicating warmer conditions than now prevail.

(Second or later glaciation, possibly, than some of the Scotch beds above.)

8. Neolithic. — Belfast and Estuarine Clays generally, not very fossiliferous.

Fossil Tertiary Polyzoa.

—	Coralline Crag	Lower Red Crag	Middle Red Crag	Upper Red Crag	Pre-glacial	Arctic	Palæolithic	Neolithic	—
Cheilostomata, *Busk*									
Cellularia, *Pallas* (pars)									
Peachii, *Busk*							*		
Menipea, *Lamx.*									
ternata, *Ell.* and *Sol.*							*		
Scrupocellaria, *Van Ben.*									
scabra, *Van Ben.*							*		
scruposa, *L.*	*						*		
var. elongata, *Smitt*							*		
reptans, *L.*						*	*		Canda
Caberia, *Lamx.*									
Boryi, *Aud.*							*		
Ellisii, *Flem.*							*		
grandis, *Hincks*							*		
rudis, *Busk*							*		
Bugula, *Oken*									
turbinata, *Ald.*							*		B. avicularia, *Pall.*
Cellaria									=Salicornaria, *Busk*
farciminoides, *Johnst.*									
fistulosa, *L.*	*	*	*						
sinuosa, *Hass.*	*	*	*				*		
Cuvieri, *Lam.*									*Fide* Shone, 1878, 'Proc. (2) Chester Soc. N. Sc.'
Melicerita, *Milne-Ed.*									
Charlesworthii, *Edw.*	*	*	*						
Membranipora									
aperta, *Busk*	*	*							
(bidens, *Hag.*	*)								See Micropora
catenularia, *Jameson*	*		*	*			*		Hippothoa c.
craticulata, *Ald.*							*		
dubia, *Busk*			*						
Dumerilli, *Aud.*	*		*				*		
fissurata, *Busk*	*								
Flemingii, *Busk*							*		
Lacroixii, *Aud.*	*		*						

Fossil Tertiary Polyzoa—continued.

—	Coralline Crag	Lower Red Crag	Middle Red Crag	Upper Red Crag	Pre-glacial	Arctic	Palæolithic	Neolithic	—
Membranipora									
lineata, *L.*							*		
membranacea, *L.*	*						*		
monostachys, *Busk*		*	*				*		
oblonga, *Busk*	*		*						
oceani, *D'Orb.*	*								
pilosa, *L.*									
rhynchota, *Busk*	*								?
Savarti, *Aud.*	*	*	*	*					
trifolium, *S. V. W.*	*	*	*				*		
tuberculata, *Bosc.*	*	*	*				*		
unicornis, *Flem.*			*			*	*		= Lepralia, *B.*
holostoma, *S. V. W.*	*								
Steganoporella, *Smitt*									
Smittii, *Hincks*	*								M. andegavensis, *Mich.*
Cribrilina, *Gray*									
annulata, *Fabr.*							*		Lepralia, pars.
figularis, *Peach*			*						
Morrisiana, *Busk*	*								
punctata, *Hass.*	*	*							
puncturata, *S. V. W.*		*							
radiata, *Möll.*	*			*					L. innominata, *Couch*
Microporella, *Hincks*									
ciliata, *Pall.*	*	*					*		
hippocrepis, *Goldf.*	*	*							M. bidens, *Hag.*
impressa, *Aud.*	*								L. pyriformis
Malusii, *Aud.*	*	*							
violacea, *Johnst.*	*	*	*						includes L. plagiopora, *Busk*
Haimesiana, *Busk*	*								
infundibulata, *Busk*	*		*						
megastoma, *S. V. W.*									
papillata, *Busk*	*								
Reussiana, *Busk*	*								
Chorizopora, *Hincks*									
Brongniarti, *Aud.*									Lep. B.
Porina									Lep. B.
tubulosa, *Norm.*									Lep.
Schizoporella, *Hincks*									
ansata, *Johnst.*	*		*						
biaperta, *Mich.*	*								
cruenta, *Norm.*							*		
hyalina, *L.*	*						*		
Milneana, *Busk*	*								
(plagiopora, *Busk*	*)								See M. violacea
pyriformis, *S. V. W.*	*	*							
sinuosa, *Busk*							*		
unicornis, *Johnst.*	*						*		
venusta, *Norm.*							*		
Mastigophora, *Hincks*									
Dutertrei, *Aud.*	*								Lep. Woodiana
Hippothoa									
abstersa, *S. V. W.*	*	*							

Fossil Tertiary Polyzoa—continued.

—	Coralline Crag	Lower Red Crag	Middle Red Crag	Upper Red Crag	Pre-glacial	Arctic	Palæolithic	Neolithic	—
Hippothoa									
dentata, *S. V. W.*	*								
divaricata, *Lamx.*	*								
Patagonica, *Busk*	*							*	
Lepralia, *Johnst.*									
divisa, *Norm.*							*		
edax, *Busk*	*	*	*						
infundibulata, *Busk*			*						
megastoma, *S. V. W.*	*								
Pallasiana, *Möll.*	*								
papillata, *Busk*	*								
Reussiana, *Busk*	*								
simplex, *Johnst.*							*		
spinifera, *Johnst.*							*		
pertusa, *Esp.*									
Umbonula, *Hincks*									
verrucosa, *Esp.*							*		
Porella, *Gray*									
concinna, *Busk*							*		
struma, *Norm.*							*		
Escharoides, *Smitt*									
Sarsii, *Smitt*							*		
Smittia, *Hincks*									
Landsborovii, *Johnst.*							*		
crystallina, *Norm.*							*		
Phylactella, *Hincks*									Alysidota
catena, *S. V. W.*	*								
labrosa, *Busk*		*							
Mucronella, *Hincks*									
Bowerbankiana, *Busk*	*								
coccinea, *Johnst.*	*								L. mamillata
lobata, *Busk*	*		*						
variolosa, *Johnst.*	*								
ventricosa, *Hass.*	*								
Peachii, *Johnst.*	*	*	*				*		
Palmicellaria, *Alder*									
Skenei, *E.* and *S.*	*								L. bicornis
Eschara, *Pallas*									
cornuta, *Busk*	*								
incisa, *M.-Ed.*	*		*						
monilifera, *M.-Ed.*	*	*	*	*					
porosa, *M.-Ed.*	*	*							
pertusa, *M.-Ed.*	*		*						
patens, *Smitt*							*		
Sedgwicki, *M.-Ed.*	*	*	*						
sinuosa, *Busk*	*	*	*						
socialis, *Busk*	*								
Biflustra, *D'Orb.*									
delicatula, *Busk*	*	*	*						
Flustra									
dubia, *Busk*	*								
avicularia, *Mont.*							*		
Hemeschara									
imbellis, *Busk*	*		*						(?) Eschara pertusa (A. B.).

Fossil Tertiary Polyzoa—continued.

—	Coralline Crag	Lower Red Crag	Middle Red Crag	Upper Red Crag	Pre-glacial	Arctic	Palæolithic	Neolithic	—
Lunularia, *Lamx.*									
conica, *Defr.*	*	*	*	*					
Cupularia									
canariensis, *Busk*	*								
denticulata, *Conr.*	*	*							
porosa, *Busk*	*								
Retepora, *Impera.*									
Beaniana, *King*	*	*	*						
cellulosa, *L.*	*								Couchi, *Hincks.*
notopachys, *Busk*	*	*							
simplex, *Busk*	*								
Cellepora, *Fabr.*									
cæspitosa, *Busk*	*	*	*						
compressa, *Busk*	*	*	*	*					
coronopris, *S. V. W.*	*	*							
dentata, *Busk*	*								
parasitica, *Mich.*	*	*	*						
pumicosa, *L.*		*			*		*		
ramulosa, *L.*	*	*							
scruposa, *Busk*	*		*						
tubigera, *Busk*	*								
Cyclostomata, *Busk.*									
Crisia									
eburnea, *L.*						*	*		
denticulata, *Lamx.*	*						*		
Alecto,[1] *Lamx.*									
dilitans, *Johnst.*	*	*	*						Tub. palmata.
compacta	*								
granulata, *M.-Ed.*	*								
major, *Johnst.*	*								
repens, *S. V. W.*		*	*	*					
Tubulipora									
{ fimbria, *Lamx.*	*		*				*		
{ flabellaris, *Fabr.*	*		*				*		
patina, *L.*							*		
phalangea, *Couch*	*		*				*		
Idmonea									
atlantica, *E F.*							*		
delicatula, *Busk*	*								
fenestrata, *Busk*	*	*					*		
intricaria, *Busk*	*	*							
punctata, *D'Orb.*	*								
serpens, *L.*							*		
verrucosa, *M.-Ed.*								*	
Entalophora									Pustuloporia.
deflexa, *Couch*	*								P. clavata, *Busk*
palmata, *Busk*	*								
subverticellata, *Busk*	*	*							

[1] Stomatopora is so like Stoomatopora, Stoastoma, that I have preferred Alecto.—Bell.

Fossil Tertiary Polyzoa—continued.

—	Coralline Crag	Lower Red Crag	Middle Red Crag	Upper Red Crag	Pre-glacial	Arctic	Palæolithic	Neolithic	—
Diastopora									
obelia, *Johnst.*							*	*	
suborbicularis, *Hincks*	*		*						Simplex, *Busk*, non *D'Orb.*
Patinella									
proligera, *Busk*	*								
Mesenteripora									
meandrina, *S. V. W.*	*								
Hornera									
canaliculata, *Busk*	*	*							
frondiculata, *Lamx.*	*	*	*						
hippolyta, *Defr.*	*	*							
humilis, *Busk*	*								
lunata, *Busk*	*								
pertusa, *Busk*	*								
infundibulata, *Busk*	*	*	*						
reteporacea, *M.-Edw.*	*	*							
rhipis, *Busk*	*	*							
striata, *M.-Edw.*	*	*	*						
rhomboidalis, *Busk*	*		*						
Lichenopora									Discoporella
hispida, *Flem.*	*					*	*		
flosculus, *Hincks*							*		
crassiuscula, *Smitt*	*						*		Grignonensis, *Busk*
Defrancia									
rugosa, *Busk*	*	*	*						
striatula, *Busk*	*								
Fungella									
infundibulata, *Busk*	*								
multifida, *Busk*	*		*	*					Only juv. of Fascic. tubip.
quadriceps, *Busk*	*	*							
Heteropora									
clavata, *Goldf.*	*	*							
lævigata, *Busk*	*	*							
pustulosa, *Busk*	*	*	*						
reticulata, *Busk*	*								
Hetereporella									
parasitica, *Busk*	*								
radiata, *Busk*	*		*				*		
Alveolaria									
semiovata, *Busk*	*	*	*						
Fascicularia									
aurantia, *M.-Edw.*	*	?	*						
tubipora, *Busk*	*	?	*						

'Miocene Polyzoa.'

Miocene Polyzoa, so abundant in Continental beds, are, I believe, unknown in the British.

'Eocene Polyzoa.'

Note on the Scarcity of Eocene Polyzoa.

Considering the richness of other sections of organic life in the Eocene, the great poverty of the Molluscoida (Brachæopoda and Polyzoa) is very remarkable, and this poverty does not arise from an oversight on the part of collectors, or for want of looking for. Some thousands of specimens having passed through the hands of one or other of us, it is possible to speak with some amount of certainty upon this head. Of the few species listed, Memb. Lacroixii, Flustra crassa, and Lunulites urceolatus are the commonest, but are by no means abundant; and the first two have a wide range in Eocene time. Neither do they occur in any quantity in the Continental Eocene fauna, as an examination of some thousands of shells from the Paris basin will expose an equal sparseness.

The cause of this absence is difficult to explain, as far as the free growing Cyclostomata are concerned, unless that the soil, or food, or other conditions of life, was not favourable for their development. For the adnate Cheilostomata, the want of such shells or adherent surfaces proper for their habitat may be sufficient cause.

Reasoning from the rich Crag fauna, it would appear that Polyzoa require certain genera of mollusca, and only certain species of these are selected, dead shells and shell banks among the bivalves especially being in demand, the *Pecten opercularis* and *Geradi*, *Pectunculus*, *Cytherea rudis*, *Pholas*, *Solen*, *Tellinas crassa* and *obliqua*, *Fusus antiquus*, *Nassa* and *Columbella*. Other genera are less so, and of these *Fissurella*, *Capulus*, *Buccinanops* (?), *Purpura*, *Tetragona*, *Ostrea*, and *Cardium* are the chief. Terebratulæ are good hunting grounds in the Coralline, but not in the Red Crag. With the exception of *Solen*, *Pectunculus*, and others, these genera are rare, or at least numerically so individually in the Eocenes, and of these it may be said that very few examples are known in a worn or 'dead' condition. Drifted shell banks are not common. Most of the species are in their native haunts, or where they have been removed, the genera, such as *Cyprina*, are not those selected for attachment.

The conditions of life again are not favourable; the Eocene of England consisting of either sharp sand or muddy clay; estuarine or freshwater beds.

Sharp sand is also unfavourable for preservation, as in the case of the Oldhaven sand at Bromley, where the *Pectunculi* are in millions, with the surfaces nearly all decorticated, and in the London clay. Casts of the shells are alone preserved (save a few portions of the test) in a pyritised condition.

There is only one other reason I can suggest for their absence, *i.e.* that the Molluscoida had reached their apogee in the cretaceous period, and only few genera and individuals represented this class of organism, till other times and conditions more favourable to their existence came in, in other words, that they were non-existent.

Mr. Bell has certainly given very fair explanations of some of the causes which prevented the full development of a Polyzoan fauna, and I am glad to be able to give currency to his views. In my fifth British Association Report I remarked that we might owe the scarcity to want of research. This, however, seems not to be the case. The following is the only list that I can supply:—

Eocene Polyzoa.

—	Thanet	London Clay	Bagshot & Bracklish	Barton	Oligocene	—
Biflustra eocenica, *Busk*		*				
Crisia (sp.)		*				
Cellepora petiolus, *Lonsd.*			*			
Diachora intermedia, *Waters*			*			
Distosaria Wetherellii, *Busk*		*				
Eschara Brongniarti, *Lonsd.*		*	*			
Flustra crassa, *Desm.*	*	*				
Idmonea coronopus, *Defr.*			*			
Lepralia (sp.)		*				
Lunulites urceolatus, *Lam.*			*			
Membranipora Lacroixii, *Sav.*		*			*	Also from the New Forest beds

Note on Professor G. SEGUENZA'S *List of Tertiary Polyzoa from Reggio (Calabria).* Rev. THOMAS HINCKS, *Annals, 'Mag. Nat. Hist.'* April 1884. (*Le formazioni terziarie, &c.* 1879 *and* 1880.)

1. Lepralia elegantissima, *Seguenza*, p. 83, pl. viii. fig. 11
= Cribrilina radiata, *Moll.* form innominata, *Couch.*
2. „ radiato-faveolata, *Seg.*, p. 129, pl. xii. fig. 20
= Microporella violacea, *Johnst.*
3. Cumulipora porosa, *Seg.*, p. 130, pl. xii. fig. 21
= Smittia trispinosa, *Johnst.*
4. Lepralia radiato-porosa, *Seg.*, p. 129, pl. xii. fig. 19
= or *var.* Schizoporella unicornis, *Johnst.*, including L. ansata, *Johnst.*
5. „ exima, *Seg.*, p. 203, pl. xiv. fig. 23, *Johnst.*
= Membraniporella nitida, *Johnst.*
6. „ calabra, *Seg.*, p. 201, pl. xv. fig. 6
= Microporella ciliata, *Pall.*
7. „ mitrata, *Seg.*, p. 203, pl. xv. fig. 8
= Cribrilina radiata, *Moll.*
8. „ coronata, *Seg.*, p. 295, pl. xvii. fig. 6.
A variety of Microporella Malusii, *Aud.* Chiefly remarkable for the curiously furrowed surface of the oœcium.
9. „ thiara, *Seg.*, p. 370, pl. xvii. fig. 57
= Cribrilina punctata.
10. Salicornaria mammillata, *Seg.*, p. 294, pl. xvii. fig. 5.
Probably a species of Myriozoum.

Mr. Hincks remarks (p. 267, *op. cit.*) that 'Professor Seguenza's work is of such sterling character, and will deservedly have so much weight with the student, that it seems peculiarly desirable to prevent these spurious species, if possible, from sheltering themselves under his authority.'

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In this paper Mr. Busk describes and well illustrates a new species, which he names *H. Neo-Zelanica*.

1880. List of Polyzoa collected by Captain H. W. Fielden in the North Polar Expedition, with description of new species. 'Linnæan Soc. Jour. Zoology,' vol. xv. Read June 1880, pp. 231–241, plate xiii. Cheilostomata, Cyclostomata, and Ctenostomata.

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Much of the matter of this paper is included in the 'Challenger Report on Polyzoa.'

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Alcide D'Orbigny.

1839. 'Voyage dans l'Amérique-Méridionale,' v. 4th part, Zoophytes.
1851. Recherches zoologiques sur la classe des Mollusques Bryozoaires. 'Ann. de Sc. Nat.,' 3rd ser. tomes xvi., xvii.

Ehlers.

1876. *Hypophorella expansa.* Abhandl. königl. Gesellsch. d. Wissensch. Gottingen, xxi.

J. Ellis.

1755. Essay towards a Natural History of Corallines.

Otho Fabricius.

1780. Fauna Groenlandica.

P. Fischer.

1866. Sur les Bryozoaires perforants. Comptes rendus. No. 18, p. 985.
1870. Bryozoaires des côtes du Sud-ouest de la France. 'Actes Soc. Linn.,' Bordeaux, xxvii.

J. E. Gray.

1848. Catalogue of Radiata in British Museum.

A. H. Hassall.

1841. Catalogue of Irish Zoophytes. 'Ann. Nat. Hist.' vol. vii.

Heller.

1867. Die Bryozoen d. Adriatsches Meeres.

Rev. Thomas Hincks, B.A., F.R.S.

1860–1862. New Polyzoa from Ireland. 'Quart. Jour. Mic. Soc.,' vol. viii.
„ „ New British Polyzoa, ibid. v.
„ „ Catalogue of Zoophytes of Devon and Cornwall. 'Ann. and Mag. Nat. Hist.'
1871. Supplement to the above. 'Ann. Mag. Nat. Hist.'
1861. Note on Ovicells of Cheilostomata, 'Quart. Jour. Mic. Soc.,' p. 278.
1872. On *Campylonema*, a new genus of Polyzoa. 'Ann. Mag. Nat. Hist.' Species of this genus was afterwards established as the family Valkeriide, and the Campylonema is the *Valkeria* (pt.), Fleming, of the 'British Marine Polyzoa,' 1880, p. 551.
1877. Polyzoa from Greenland and Labrador. 'Ann. Mag. Nat. Hist.,' January.
„ On British Polyzoa, Part I. 'Ann. Mag. Nat. Hist.,' September.
„ On British Polyzoa, Part II. *Op. cit.* December (Classification).
1878. Notes on the genus Retepora, with descriptions of new Species. 'Annals and Mag. Nat. History,' 5th ser. vol. i. 2 plates, pp. 353–365.

In this paper the author describes nine species of *Retepora*, five of which are new—*R. Couchii*, *R. prœtenuis*, *R. plana*, *R. tessellata*, and *R. robusta*—and he gives very full details of the other four. Mr. Hincks also gives a brief account of the previously described species of authors. As usual, the new and some of the known species are illustrated as well as described.

1879. On the Classification of the British Polyzoa. 'Ann. Mag. Nat. Hist.' 5th ser. vol. ii. pp. 153–164.

This is a paper on 'certain portions of the Classification adopted in the History of the British Marine Polyzoa.'

1880. 'A History of the British Marine Polyzoa,' 2 vols. Vol. i., text; vol. ii., plates.

In this work Mr. Hincks describes and figures every known species of British Ctenostomata, Cheilostomata, and Cyclostomata. The work should be consulted by every student who desires to make known to science the species found in many of the still partially known British localities.

1880. Note on a supposed Pterobranchiate Polyzoon from Canada. 'Ann. Mag. Nat. Hist.' 5th ser. vol. vi. p. 239.

1880. Contributions towards a General History of Marine Polyzoa. 'Ann. Mag. Nat. Hist.' 5th ser. vol. v. pp. 69–91, plates ix., x., xi.

In this paper Mr. Hincks describes, Part I. Madeira species which belonged to the cabinet of J. Y. Johnson, Esq., of Madeira. Some of the collection had been previously described by Mr. G. Busk. Mr. Hincks, however, makes many additions to Mr. Busk's list. Part II. Foreign Membraniporidæ.

1880. On New Hydroida and Polyzoa from Barrent's Sea. 'Ann. Mag. Nat. Hist.' 5th ser. vol. v. pp. 277–286, plate xv.

A full list of the Polyzoa obtained by Mr. W. J. A. Grant in the Arctic Sea was given in the same volume of the 'Annals.' Mr. Hincks's paper contains a detailed description of the new forms which occur in the collection. Among the Ctenostomata one new genus—*Barrentsia*, Hincks—is described, and a new species—*B. bulbosa*, Hincks.

1880. Foreign Membraniporidæ. 'Ann. Mag. Nat. Hist.' Nov., 5th ser. vol. vi. pp. 376–381, plates xvi. and xvii.

Besides the Membranipora, Mr. Hincks describes *Steganoporella* and species referable to the genus. Pt. II. Foreign Cheilostomata, Miscellaneous.

1881. Contributions towards a General History of Marine Polyzoa. I. Foreign Membraniporina; II. Foreign Cheilostomata. 'Ann. Mag. Nat. Hist.' 5th ser. vol. vii. plates viii., ix., x. pp. 147–161.

In this paper Mr. Hincks established the family *Epicaulidiidæ* and the genus *Epicaulidium* for a species which was afterwards withdrawn; and a new genus of the *Escharidæ*—*Aspidostoma*, Hincks.

1881. On a Collection of Polyzoa from Bass's Straits, presented by Capt. W. H. Cawne-Warren to the Liverpool Free Museum.

A paper read before the Lit. and Phil. Soc., Liverpool, April 18, 1881, pp. 1–22.

1881. Polyzoa of Bass's Straits (Contributions), 'Ann. Mag. Nat. Hist.' July, vol. viii. plates i., ii., iii.

The collection of Capt. Warren contained ninety-two species, twenty-two of which are European.

1881. Contributions, &c. 'Ann. Mag. Nat. Hist.' 5th ser. vol. viii. plates iv. and v. pp. 122–136.

In this paper Mr. Hincks continues his descriptions of species from Bass's Straits, and then afterwards his descriptions of Foreign Membraniporina (third series) and Foreign Cheilostomata. Several species of *Diachoris* are described, and the genus and species of Epicaulidium are withdrawn.

1882. On certain remarkable modifications of the Avicularium in a species of Polyzoon, and on the relation of the Vibraculum to the Avicularium. 'Ann. Mag. Nat. Hist.' 5th ser. vol. ix. pp. 20-25. Several woodcuts, no plate.

„ Contributions, &c. Foreign Cheilostomata (miscellaneous). 'Ann Mag. Nat. Hist.' 5th ser. vol. ix. plate v. pp. 79–90.

Several new species are described from different localities, most of which are from the cabinet of Miss E. C. Jelly.

1882. Contributions, &c. 'Ann. Mag. Nat. Hist.' August. 5th ser. vol. x. p. 160, plates vii. and viii.

In this paper Mr. Hincks describes (family Eucratiidæ) a new genus, Rhabdozoum, for the reception of a species, *R. Wilsoni*, from Port Phillip Heads. In the family Membraniporidæ a new genus, *Euthyris*, and a new species, *E. obtecta*, from Australia. Besides these other species of Foreign Polyzoa are described.

1882. Preliminary notice of new species of Polyzoa from Queen Charlotte Islands. In the paper 21 new species are described but not illustrated. 'Ann. Mag. Nat. Hist.' Sept., pp. 248–256.

„ Polyzoa of the Queen Charlotte Islands. Part I. December. 'Ann Mag. Nat. Hist.' plates xix. and xx. 5th ser. vol. x.

1883. Contributions, &c. Foreign Cheilostomata from Australia and New Zealand. Describes two new genera, *Stiparia*, Goldstein, and *Stolonella*, Hincks. 'Ann. Mag. Nat. Hist.' p. 193, plates vi. and vii. March.

„ Polyzoa of Queen Charlotte Islands. Part II. June. 'Ann. Mag. Nat. Hist' 5th ser. vol. xi. plates xvii. and xviii.

1884. Continuation of above. Part III. January. 'Ann. Mag. Nat. Hist.' 5th ser. vol. xiii. plates iii. and iv.

„ Completion of Report on Polyzoa of Queen Charlotte Islands. 'Ann. Mag. Nat. Hist.' 5th ser. vol. xiii. plate ix. Cyclostomata, Ctenostomata, and Addenda.

„ Report on the Polyzoa of the Queen Charlotte Islands. Ottawa: MacLean, &c. Published in connection with other works on the Geological and Natural History Survey of Canada, pp. 1–44, and the whole of the plates.

The above work is a reprint of the four papers and seven plates originally published in the 'Annals,' December 1882, June 1883, January and March 1884. In the Report ninety-six species are recorded, thirty-six of which had not been previously described.

1884. Note on Professor G. Seguenza's List of Tertiary Polyzoa from Reggio (Calabria). 'Ann. Mag. Nat. Hist.' April, 5th ser. vol. xiii. pp. 265–267.

„ Contributions, &c. XII. Polyzoa from India (coast of Burmah). XIII. Polyzoa from Victoria and Western Australia. 'Ann. Mag. Nat. Hist.' 5th ser. vol. xiii. pp. 356–369, plates xiii. and xiv.

The paper contains descriptions of Cheilostomata and Ctenostomata.

1884. Contributions, &c. XIII. Polyzoa of Victoria, continued. 'Ann. Mag. Nat. Hist.' October 1884, pp. 276–285, plate ix.

In this paper Mr. Hincks describes a new family of Cheilostomata, Cyclicoporidæ, and a new genus, *Cyclipora*, for the reception of the species, C. prælonga, Hincks.

1885. Contributions, &c. Polyzoa from New Zealand and Australia. 'Ann. Mag. Nat. Hist.' March 1885, vol. xv. pp. 244–257, plates vii.–ix.

A. HYATT.

1866. } Observations on Polyzoa. Sub-order Phylactolemata. 'Proc. Essex Inst.'
1868. } iv. p. 197.

G. JOHNSTON.

1847. 'History of British Zoophytes,' 1st edit.
1849. „ „ „ 2nd edit.

KIRCHENPAUER.

. East Greenland Polyzoa, in 'Die zweite deutsche Nordpolarfahrt.'

J. V. LAMOUROUX.

1816. Nat. Hist. 'Des polypiers coralligéries flexibles,' &c.

LANDSBOROUGH.

1852. Popular History of British Zoophytes.

P. H. MACGILLIVRAY.

'On some new Australian Polyzoa.' By P. H. Macgillivray. Read before the Institute, August 3, 1859.

'Notes on the Cheilostomatous Polyzoa of Victoria and other parts of Australia.' By P. H. Macgillivray. Read before the Institute, October 26, 1859.

'On two New Genera of Polyzoa.' By Macgillivray. Read April 15, 1880.

'On some New Species of Catenicella and Dictyopora; and on Urceolipora, a new genus of Polyzoa.' Read November 18, 1880.

'Descriptions of New or Little-known Polyzoa.' Part I. Read December 9, 1881.

Ibid. Part II. July 13, 1882.
Ibid. Part III. October 12, 1882.
Ibid. Part IV. December 14, 1882.
Ibid. Part V. August 9, 1883.
Ibid. Part VI. December 13, 1883.
Ibid. Part VII. (No date.)
Ibid. Part VIII. November 20, 1884.

F. M'COY.

'Prodromus of the Zoology of Victoria.' By F. M'Coy.

Decades III., IV., V., VI., VII., VIII., IX., all contain papers on the Victorian Polyzoa; and Mr. Waters tells us that another is out, containing the Reteporæ, so I suppose that will be X., but I have not seen it yet.

W. C. MCINTOSH.

1877. Marine Fauna of St. Andrews.

Dr. A. MANZONI.

1871. Supplem. alla Fauna dei Bry. Medit.

Rev. A. M. NORMAN.

1864. On Undescribed British Actinozoa, Hydrozoa, and Polyzoa. 'Ann. Nat. Hist.' January.
„ Notes on Rare British Polyzoa. 'Quart. Jour. Mic. Soc.' VIII. N.S.
1866. Report on Hebridian Polyzoa. 'Brit. Assoc.'
1868. Last Report on Shetland Dredgings. 'Brit. Assoc.'

A. S. PACKARD.

1863. List of Animals dredged near Cariboa Island, South Labrador. 'Canad. Nat. and Geol.' viii. No. 6.

PALLAS.

1766. Elenchus Zoophytorum.

PARFITT.

1866. Fauna of Devon. Zoophytes.

G. O. SARS.

1869. On some Remarkable Forms of Animal Life from the Great Depths off the Norwegian Coast.
1874. Reprinted, 'Quart. Jour. Mic. Soc.' January.

F. A. SMITT.

1863. Om Hafs-Bryozoeras Utvekkling Upsala.
1865. „ „ „ och Fettkropper.
1864. Kritisk Förteck ning öfver Scandinaviens.
1868. Hafs-Bryozoen. I. *Cyclostomata.*
„ II. *Cyclostomata*, continued, and *Ctenostomata.*
„ III. *Cheilostomata*, and
„ IV. „ continued.
1867. Bryozoa marina in regionibus arcticis et borealibus viventia.
1872. Floridian Bryozoa. Kongl. Svenska Velenskaps Handl.

WATERS, A. W., F.G.S.

1878. On Bryozoa. Manchester Lit. and Phil. Soc., Microsc. and Nat. Hist. Sect., vol. xvii. pp. 125–138.

In this paper Mr. Waters reviews as a popular outline of the class Polyzoa the zoological position of the various groups, detailing at some length his reasons for adopting the term *Bryozoa* instead of *Polyzoa.*

1878. On the Use of the Opercula in the Determination of the Cheilostomatous Bryozoa. 'Proc. Manchester Lit. and Phil. Soc.' vol. xviii.
1879. On the Bryozoa (Polyzoa) of the Bay of Naples. 'Ann. Mag. Nat. Hist.' 5th ser., vol. iii. pp. 28–43, plates viii. and xi. Part I. reviews the literature of the subject, and describes 32 species of *Lepralia* (old nomenclature) and one *Eschara.*
1879. Bryozoa of the Bay of Naples. Part. II. Cheilostomata, continued. *Op. cit.* February, pp. 114–126, plates xii., xv.

Describes twenty-eight species of various genera.

1879. Bry. Bay. Nap, Pt. III. *Op. cit.* pp. 192–202.

Describes thirteen species of *Cellepora*, two of *Retepora* and *Myrozoum truncatum*, Pallas.

1879. Bry. Bay. Nap. Pt. IV. Cyclostomata and Ctenostomata. *Op. cit.* pp. 267–281, plates xxiii., xxiv.

Describes thirty-three species, in all 111 species of Bryozoa, as found in the Bay of Naples. In the whole of these papers Mr. Waters gives a very full synonymous list and references, both fossil and recent, and a very valuable list of localities in which the species are found.

1880. On the terms *Bryozoa* and *Polyzoa*. 'Ann. Mag. Nat. Hist.' January, pp. 1–3.
1879. On the occurrence of recent *Heteropora*. 'Jour. Mic. Soc.' vol. ii. pp. 390–393, pl. xv. Paper read May 1879.

A very important paper giving details of structure of *Heteropora*, both recent and fossil. Describes as new *H. pelliculata*, Waters, and re-describes *H. cervicornis*, D'Orb.

1880. Note on the genus *Heteropora*. 'Ann. Mag. Nat. Hist.' vol. vi. p. 156.
1884. Closure of the Cyclostomatous Bryozoa. 'Linnæan Soc. Jour. Zoology,' vol. xvii. pp. 400–404, pl. 17.

STUART O. RIDLEY.

1881. Account of the zoological collections made during the survey of H.M.S. 'Alert' in the Straits of Magellan and on the coast of Patagonia. Proceedings of the Zoological Society of London, January. In two parts: I. Polyzoa, pp. 44-61, pl. vi.; II. Cœlenterata, pp. 101-107.

In the Polyzoa part, Mr. S. O. Ridley establishes a new genus—*Gigantopora*, Ridley—for the placement of a species described and figured *G. lyricoides*, Ridley; and in his observations he says that *Hippothoa fenestrata*, Smitt, 'Flor. Bryoz.' must also be ranked under the genus.

1881. Polyzoa, Cœlenterata, and Sponges of Franz Josef Land. 'Ann. Mag. Nat. Hist.' June, pp. 442-457, pl. xxi.

Several species of Cheilostomata and three of Cyclostomata are described, amongst the latter young colonies of what Mr. Ridley believes to be *Heteropora pelliculata*, Waters (?). 'This genus,' says the author, 'is already known from New Zealand, Australia, and the Japanese seas, and in the fossil state: its recent distribution is now extended to the Arctic seas,' p. 453.

1882. Notes on Zoophytes and Sponges obtained by Mr. F. Day off the east coast of Scotland. 'Linnæan Soc. Jour. Zoology,' vol. xvii. pp. 105-108.

Contains a brief note on Polyzoa.

I am fully aware that there are several bibliographical papers omitted in the above list. Many of these, however, are particularly of a structural character, and I was in hope that I should have been able to include these, with special remarks upon them, in some future Report. At present my labours are so far complete up to this point only. The structural peculiarities of several polyzoal groups, together with remarks on the Ctenostomata, must remain in abeyance, for the present at least. There are a few papers not recorded above that may be specially referred to. Dr. Jullien's work on 'Recent Species' I was not able to procure or even get a sight of; and equally inaccessible were D'Orbigny's 'Descriptions of South American Polyzoa'; the writings of Krauss, Meneghini, W. Stimpson's 'Invertebrata of Grand Manon,' Verrill's 'Recent Additions to Marine Invertebrata,' or Risso's 'Fauna of the Mediterranean,' &c. Mr. Quelch's labours on the group, however, may be mentioned, though his writings may be few in number. His remarks on *Spiralaria*, Busk—a peculiar polyzoon not as yet classified—and on certain species of *Schizoporella* ('Ann. Mag. Nat. Hist.' 1884), merit attention; so also references to Dr. Jullien's labours in Mr. A. W. Waters's papers on 'Fossil Bryozoa'; and special reference should be made to the article on Polyzoa in the 'Encyclopædia Britannica,' by Dr. Ray Lankester, F.R.S. Another paper by Mr. A. W. Waters, F.G.S., just to hand (November 1885), may be mentioned. This is one on the 'Avicularian Mandibles,' &c. and a very important one withal.—*Journ. Roy. Mic. Soc.* Ser. 2, vol. v. pp. 774-779.

Third Report of the Committee, consisting of Sir J. HOOKER, Dr. GÜNTHER, Mr. HOWARD SAUNDERS, *and* Mr. SCLATER (*Secretary*), *appointed for the purpose of exploring Kilima-njaro and the adjoining Mountains of Equatorial Africa.*

1. IN their last report, presented at Montreal, the Committee stated the arrangements that they had made with Mr. H. H. Johnston for undertaking an expedition to Kilima-njaro, and gave extracts from Mr. Johnston's letters showing the progress of his expedition up to May 1884.

2. Mr. Johnston returned to this country in December last, and gave an account of his expedition to the Royal Geographical Society at their meeting on January 26, 1885,[1] which is published in their Journal.

3. Mr. Johnston there tells us he was much hampered, as regards collecting, by the desertion of two natives whom he had taken out with him from Zanzibar as collectors. The consequence of this was that the collections, although containing many objects of great interest, are not so large as the Committee could have wished.

4. The Committee requested Captain Shelley to prepare a report on the birds collected by Mr. Johnston, and Mr. F. D. Godman on the butterflies of his collection, after which the first sets in both these collections were handed over to the British Museum.

5. All the other zoological collections were likewise handed over to the British Museum, with a request to the Director that reports might be prepared for publication on such portions of them as seemed to be of sufficient interest.

6. The following reports on the zoological collections made by Mr. H. H. Johnston have already been published in the 'Proceedings' of the Zoological Society for this year:—

(1) General Observations on the Fauna of Kilima-njaro. By H. H. Johnston. P.Z.S., 1885, p. 214.

(2) Report on the Mammals obtained and observed by Mr. H. H. Johnston on Mount Kilima-njaro. By Oldfield Thomas, F.Z.S. P.Z.S., 1885, p. 219.

(3) On the Collection of Birds made by Mr. H. H. Johnston in the Kilima-njaro District. By Captain G. E. Shelley, F.Z.S.; with Field-notes by Mr. H. H. Johnston, F.R.G.S. P.Z.S., 1885, p. 222.

(4) On the Insects collected on Kilima-njaro by Mr. H. H. Johnston. By Charles O. Waterhouse. P.Z.S., 1885, p. 230.

(5) Note on a Nematoid Worm (*Gordius verrucosus*) obtained by Mr. H. H. Johnston on Kilima-njaro. By F. Jeffrey Bell, M.A., F.Z.S. P.Z.S., 1885, p. 236.

(6) Description of a New Variety of River-Crab, of the genus *Thelphusa*, from Kilima-njaro. By E. J. Miers, F.L.S., F.Z.S. P.Z.S., 1885, p. 237.

(7) A List of the Lepidoptera collected by Mr. H. H. Johnston during his recent expedition to Kilima-njaro. By F. D. Godman, F.R.S., &c. P.Z.S., 1885, p. 537.

7. The botanical collections were handed over to the Royal Herbarium at Kew, where they have been arranged and named. A set of them has been sent to the British Museum. The report upon them is ready, and will be presented to the Linnæan Society for publication.

[1] See *Journ. Proc. Roy. Geogr. Soc.*, 1885, p. 137.

8. Professor Bonney has kindly undertaken to report on the rock and mineral specimens collected by Mr. Johnston, and his report is presented herewith, and will be read in the Geological Section.

9. Mr. H. H. Johnston has in preparation a volume containing a narrative of his expedition and a summary of the results arrived at, which will shortly be ready for issue.

10. The sum of 25*l.* granted to the Committee at the Montreal meeting has been returned to the Treasurer.

APPENDIX.

Report on the Rocks collected by H. H. Johnston, Esq., from the upper part of the Kilima-njaro massif. By Professor T. G. Bonney, *D.Sc., F.R.S., Pres. G.S.*

The collection consists of forty rock and six mineral specimens—most of them rather small pieces—which in several cases have evidently not been broken from rocks *in situ*, but have been lying about on the ground as loose fragments.

(1) *Stream Valley, Kilima-njaro*, 13,000 feet (16 fragments).—These are rolled pebbles or fragments, more or less waterworn, varying in diameter from about three-quarters of an inch to one and a-half inch. They consist of a black glassy rock, of a very dark grey subvitreous rock, or an extremely compact lava (all obviously not very different from glassy basalts), together with five specimens of more or less scoriaceous rock, the last named being more waterworn than the other. These are a dark compact rock, containing crystals (sometimes quite an inch long) of a glassy felspar in rather tabular crystals, which is probably identical with one to be presently described. Of the former group I have selected three for microscopic examination as being fairly representative of the series.

(*a*) Fragment (somewhat rounded) of black glass of slightly resinous lustre, with faint indications of a fluidal structure. Examined microscopically, it appears as a banded brown glass, varying in colour from a rather pale to a warm brown tint. Both, but especially the latter, are streaked with elongated trichites of dark brown to black colour, and the darkest band is beautifully 'marbled' by darker streaks and filamentous trichites. Scattered about are acicular microliths; some of the smaller and thinner are probably felspar, but certain of the larger show good hexagonal sections, and may be safely identified as apatite. Three or four rounded grains, associated twice with apatite and once with magnetite (?) also occur. They are either olivine or augite—I think the latter; neither cleavage nor external form is sufficiently definite to enable me to speak with certainty. I regard them as the remnants of crystals, of which the external angular portion has been melted away. The rock may be classed with the augite-andesite glasses, and belongs to the more basic side of the group.

(*b*) A similar rock, but with a rather duller lustre. Examined with the microscope under a low power, it seems to be a rather opaque-looking darkened grey glass. With high powers, there appears to be a base of clear glass from which the magnetite has separated in minute granules and 'dusty' patches and a number of very minute belonitic crystals, probably felspar, have formed. There are slight indications of fluidal structure. In the slide is a perfectly round grain of hornblende, a fragment or two of felspar, a few small crystals of apatite (?), and two bits

of scoria, evidently picked up by the molten rock. These resemble an andesite, being full of plagioclase microliths, and one of them contains two larger broken plagioclase crystals.

(*c*) Is a very compact, almost black rock, without vitreous lustre. Examined with the microscope, it is seen to be very similar to the last, except that the separation of the minerals has proceeded a little further; the opacite granules and felspar microliths being slightly larger. There are one or two crystals in the slide of larger size; felspar, broken looking, magnetite and apatite.

(2) *Central Ridge, Kilima-njaro*, 14,000 feet (7 specimens of rock, 1 mineral).—Of the rock specimens (*a*) two are rather rounded; a very compact, dark grey, almost black rock. (*b*) Three flattish, rather scoriaceous fragments, two of them having a very marked platy structure, so that at first sight they might be taken for stratified. (*c*) Two are soft fragments of a dark brown compact rock (seemingly rather decomposed), containing crystals, more than half an inch in diameter, of a rather glassy felspar.

(*a*) I have examined slices from each of these. One of these differs very little from that last described, 1 (*c*), except that there seems to be a general tendency to form minute spheroids (without a radial crystalline structure), coated externally with a film of iron oxide. The other specimen belongs, no doubt, to a similar rock, as its glassy base is now crowded with elongated microliths of a plagioclastic felspar and granules of magnetite. The slide contains two crystals of brown hornblende, one or two crystals of nearly colourless augite, and a few minute patches, probably of brown glass. (*b*) I have not examined these microscopically, as they appear to me only more scoriaceous forms of (*a*). (*c*) One of these has been examined. The ground mass has a general resemblance to that of the first specimen in (*a*), but appears rather more decomposed. In this occur a few grains of a nearly colourless mineral, some certainly augite, though olivine may also be present. The former appears once or twice to have been more or less replaced by magnetite, which mineral also occurs in independent crystals, and there is a little apatite. The large felspar crystals, two of which are partly included in the slide, are worn and rounded at the edges and have several inclusions of the ground mass. They present a general resemblance to sanidine.

The separate crystal of a mineral has evidently been detached from a similar rock; it is about four-thirds of an inch long and rather more than half an inch wide. It bears a general resemblance to sanidine, but the form is a very peculiar one for this mineral to assume. The faces of ∞P are well developed, OP rather small, together with another face in the vertical zone; $\infty \breve{P} \infty$ small. Distrusting my own opinion, I referred the crystal to my friend Mr. T. Davies, of the Mineral Department of the British Museum. He at once intimated that the form was very unusual, and, after consultation with the other officers of the department, wrote to me that the crystal was a variety of orthoclase. This, with some others mentioned below, will, I hope, be described more at length by Mr. Miers at the next meeting of the Mineralogical Society.

Stones of Kimawenzi (3 specimens).—These specimens appear to be of a very similar rock, and are all more or less decomposed. They are practically identical with 2 (*c*), so I have not had a slide cut. They also contain good-sized crystals of the same peculiar felspar.

Stone, base of peak, Kimawenzi, 14,700 feet.—Slab about $6\frac{1}{2}'' \times 4\frac{1}{2}'' \times \frac{1}{2}''$

of a compact, very dark grey rock, weathered externally to a paler colour. In it are scattered a fair number of crystals of black hornblende (?) up to about $\frac{1}{4}''$ in longest diameter. Except for a mere external film, the rock is in good condition.

Under the microscope a clear glassy base is seen thickly crowded with microliths of plagioclase felspar, granules and small crystals of augite, and granules and grains of magnetite. Four of the larger crystals of hornblende are present in the slide; these have a worn, corroded look externally, and are black bordered; they are a rich olive-brown colour. There are also two crystals of light-coloured augite of about the same general size as the hornblende—one with fairly well defined angles, not black bordered; the other less perfect, with some appearance of a black border; also a smaller one which seems to include at one side a fragment of hornblende. The rock is an augite-andesite, containing some hornblende of anterior consolidation.

Rocks from base of Kimawenzi, 15,000 feet (2 specimens).—Of these rocks one is a dark, decomposed, compact rock like 2 (*c*); the other contains the same felspar, but is paler in colour. I have not had these cut for the microscope.

Rocks from base of Kibo, 14,000 feet (8 specimens of rocks, 4 specimens of minerals.—The rocks are externally a good deal decomposed, and closely resemble those from the base of Kimawenzi and from the central ridge 2 (*c*). I have had a slice prepared from the one which seemed in best preservation. The base is a dark brown glass of rather decomposed aspect, in which are scattered minute felspar microliths as already described. There are several small vesicles visible in the slide, together with minute circular spots of an isotropic mineral, probably yet smaller cavities filled up by some secondary products. Parts of two of the peculiar felspar crystals already mentioned occur in the slide. Externally they have a rather rounded aspect, internally there are many inclosures of the base. They have a general resemblance to sanidine, but one shows rather distinctly a peculiar cross-hatched structure not unlike that of microcline. The mineral specimens are all pieces of separate crystals of this felspar, which have probably been about the same size as that described from the central ridge. They are, I am informed, like it, a variety of orthoclase, and some exhibit twinning, the composition face being the orthopinakoid.

Three specimens without any label. Bad specimens of a rock very similar to the last described.

As will be seen from the above notes, the collection of rocks from these interesting localities indicates (1) that the highest peaks of the Kilima-njaro *massif* consist of rather basic rocks; (2) that these rocks are all of them more or less vitreous, a glassy base having been discerned in all that have been examined; (3) that these rocks fall into two groups; (*a*) dark, glassy, or scoriaceous rocks, never showing much more than a microporphyritic structure—varieties of augite-andesite, more or less glassy; (*b*) brownish to greyish rather slaggy rocks, containing the above-described large crystals of a glassy variety of orthoclase. The base is evidently not rich in silica, and does not, I suspect, materially differ from that of the other group, so that I should regard these as intermediate between the normal augite-andesites and the normal sanidine-trachytes, and name them provisionally orthoclase-bearing augite-andesites. Mr. Johnston's collection is, I think, sufficiently ex-

tensive and numerous to justify us in assuming that the upper part of the Kilima-njaro *massif* chiefly consists of one or the other of these two allied groups of rocks; the only point of special interest in them being the abundant occurrence of this peculiar variety of orthoclase.

A fragment of a crystal, found in 'Stream Valley' at about 8,000 feet on Kilima-njaro, 'much coveted by the natives for ornaments, and said to be found only after heavy rains,' is simply rock-crystal (quartz). This mineral appears to indicate the presence of more siliceous rocks than the above; not improbably of either granite, gneiss, or some kind of schist.

P.S.—While the above description was in the press, another specimen reached me, which had previously been mislaid. It is labelled 'Found in a stream valley on Kilima-njaro,' and is a fragment, smoothed on all sides but one, of a black lava, in most parts very vesicular, the longest diameter being about $3\frac{1}{2}$ inches. It is evidently either a rather basic augite-andesite glass or a basalt glass; probably the former, like other specimens described above.

Report of the Committee, consisting of Mr. John Cordeaux (*Secretary*), Professor A. Newton, Mr. J. A. Harvie-Brown, Mr. William Eagle Clarke, Mr. R. M. Barrington, *and* Mr. A. G. More, *appointed for the purpose of obtaining (with the consent of the Master and Brethren of the Trinity House and the Commissioners of Northern and Irish Lights) observations on the Migration of Birds at Lighthouses and Lightvessels, and of reporting on the same.*

The General Report[1] of the Committee, of which this is an abstract, forms a thick pamphlet of 186 pages, and comprises observations taken at lighthouses and lightvessels, as well as at several land stations, on the coasts of Great Britain and Ireland, and the outlying islands; also from Heligoland, two stations in the Baltic, the Faroe Islands, and Iceland. Independent notes and observations have also been received from several ocean steamships in the Atlantic and Polar seas.

Altogether 193 stations have been supplied with printed schedules for registering observations, and returns have been sent in from 118. The number of schedules returned from each station varies considerably, and is in some degree dependent on the interest taken in the subject by the observers, but chiefly perhaps on the position of the station being favourably or otherwise situated for observation.

The usual number of schedules returned from a station is one or two; in many cases this is greatly exceeded. The Pentland Skerries, Isle of May, and Inner Farn Island lighthouses, have sent in fourteen, twelve, and nine respectively. The total number of schedules returned is greatly in excess of previous years, and the labour of arranging, tabulating, and reporting thereon has been considerably increased.

The Committee have this year added a new feature to their report in an outline map of the British Isles, showing the stations, marked in red. This map has been prepared by Messrs. McFarlane and Erskine, of Edin-

[1] *Report on the Migration of Birds in the Spring and Autumn of* 1884. West, Newman, & Co., 54 Hatton Garden, London, E.C.

burgh. It will prove a useful and valuable addition to the report, and a great assistance to readers and observers.

The report shows that on the east coast of England a great movement was carried on for six months in the autumn and winter of 1884–5 The schedules returned indicate that no one place had special preference, and that the inflow of migrants was equally distributed over the entire coast line.

The southerly movement of migrants was well established in July, and from this time to the end of the third week in January 1885 there was a steady flow, with slight intermissions, of birds either passing along the coast to the south or moving directly inland, the vast majority coming from the east across the North Sea, and moving westward or in westerly directions. Occasionally there have been heavy rushes or persistent bird waves, continuous for days and even weeks.

The periods of migration occupied by different species vary greatly, from four weeks to as many months; no general rule can be laid down in this respect.

There was an immense and continuous rush on to the coast from the middle of October (15th) to the end of the month, migrants arriving continuously night and day. This rush was continued at some of the stations with but slight intermissions to the middle of November.

On the east coast of Scotland, whilst desultory movements continued during September and October, the heaviest rushes are recorded in the middle of November.

The last fortnight in October is the average annual period of what may be called the 'great rush' of immigrants on to the east coast of England.

In previous reports attention has been drawn to the fact of a migration in opposite directions going on at the same time over the North Sea. This is observed more particularly at south-eastern stations, on light-vessels moored at many miles distance from the nearest land, where, during the spring and autumn, the same species of birds, as crows, rooks, jackdaws, starlings, larks, sparrows, buntings, and finches, are recorded crossing the North Sea, moving from opposite quarters and passing both towards the British coast and towards the Continent. This apparently abnormal movement in opposite directions is again indicated in the autumn and spring of 1884–5.

With very few exceptions, the vast majority of our British birds, such as are generally considered habitual residents—the young invariably, the old intermittingly—leave these islands in the autumn, their place being taken by others, not always necessarily of the same species, coming from more northern latitudes, or from districts of Eastern Europe, where, on the approach of winter, the conditions of locality and food-supply are found less favourable to existence. These immigrants on the approach of spring leave, moving back to the Continent on the same lines, but in the reverse direction to those traversed in the autumn; at the same time, also, our own birds return from the Continent to their nesting-quarters in these islands.

The notes under the head of separate species indicate several movements of special interest. Blackbirds have crossed the North Sea in extraordinary numbers, commencing on September 12 and throughout October, and immense numbers in November; on the 11th, 12th, and 13th the rush appears to have been continuous, night and day, over the whole coast line; after this intermittent to the end of the third week in January 1885.

Another very interesting feature is the occurrence of the Arctic bluethroat in considerable numbers between September 8 and 18; eighty to one hundred were observed in one locality on the Norfolk coast on the 12th.

The migration of the gold-crested wren was very pronounced. The first are recorded on August 28, and after this at various stations up to November 22.

It is rather remarkable that, with one exception (gold-crests seen inland in North-east Lincolnshire, on November 22, which may have arrived at an earlier date), the migration of this small species on the east and west coasts of England commenced at the same date, August 28, and also ended on the same date, November 16.

On the night of October 4, the time of the total eclipse of the moon, during the hours of greatest darkness, between 9 and 12 P.M., as observed by a member of the Committee,[1] gold-crests were striking the lantern of the Isle of May lighthouse. There is evidence also of other rushes of gold-crests at some of the Scotch stations during the hours of the eclipse. On the Irish coast the same night, at the South Maiden's lighthouse twenty struck at 10 P.M., and at Rathlin Island lighthouse the same number were taken at midnight.

Pied flycatchers arrived in large numbers from August 16 to September 17. Across Heligoland also there was a great migration between the same dates.

Reference is also made in the report to the great arrival of this species during the first week in May, 1885, observed at stations ranging from Yarmouth to the Pentland Skerries. At Flamborough the flycatchers arrived with a N.E. wind, and were accompanied by male redstarts. In their next report the Committee hope to be able to give full details of this remarkable immigration.

Immense numbers of ring-doves are shown to have crossed from the Continent between October 21 and the end of November. This immigration appears to have covered the coast between Berwick and Yarmouth; on our northern coast, for nine days, between November 20 and 28, the rush was continuous. Large numbers of stock doves also crossed during the same period.

The main body of woodcocks generally arrive in two flights, known to east-coast sportsmen as the 'first flight,' and after this the 'great flight.' In the autumn of 1884 the immigration of this species was most prolonged, commencing on September 1, and continuing onward to January 20, 1885, or 142 days. Four distinct rushes or flights are indicated: October 5 and 6, another on the 10th to the 16th, a third, probably the 'great flight,' on the 28th; and again a very large flight between November 11 and 13—a flight which also extended very far north, to the Pentland Skerries. The dates of the chief flights across Heligoland will be found to correlate very closely with the arrivals on the east coast. Very few woodcocks are recorded from the west coast of England. The notes, however, taken from October 8 to 14, at the Nash East Lighthouse in the Bristol Channel, on this species are very interesting. The mean time of arrival may be fixed at 3.30 A.M. On the 8th a bird, after flying round the light, went off in a south-westerly direction. It is fair to presume that these woodcocks formed part of the great flight which we know

[1] Mr. J. A. Harvie-Brown.

crossed Heligoland from the 12th to the 15th, and are also shown to have arrived on the east coast between October 10 and 16. Woodcocks migrate by night, and probably start on their journey in the dusk of evening. Supposing them to have left the coast of Denmark at 5 P.M., and travelling from north-east to south-west across Heligoland, so as to arrive at the Nash light at or about 3.30 A.M., the distance traversed would be 550 miles in $10\frac{1}{2}$ hours, or about 52 miles an hour, a rate of progress, from what we know of the flight of birds, probably nearly the correct one. A large majority of the various birds which strike the lanterns of west coast lighthouses do so between midnight and daybreak, which is suggestive of a continuous and uninterrupted flight across the North Sea and the breadth of England.

An unusually extensive migration of gulls to the Scotch coasts was remarked in 1884, in connection with the vast swarms of sprats or 'garvies' (*Clupea sprattus*), themselves following and feeding on countless myriads of minute marine creatures. This aggregation has been attributed, and perhaps with reason (though it is a point on which the Committee has not sufficient information to decide), to the vast accumulation of ice west of Spitzbergen in the summer of 1884, and the consequent lowering of the temperature of the sea, which cause has impelled and driven southward the fish food along the course of the milder Gulf Stream to the uttermost limits of its possible extension, the firths and inlets of the east coast of Scotland.

As a rule very few of our rarer immigrants are recorded from the east coast of Scotland. The king-eider was seen off the Isle of May on September 24, and the black redstart is recorded from the same station and Pentland Skerries. On the east coast of England, besides the bluethroats, already noticed, several rare and casual visitants have been recorded during the autumn: two examples of the barred warbler, one at Spurn Point and another on the Norfolk coast; the icterine warbler, also on the Norfolk coast; and an ortolan, likewise from the same locality. The Lapland bunting, in Lincolnshire and Norfolk; Tengmalm's owl, in Holderness; and a rose-coloured starling, near Spurn.

On the west coast of England the report embraces notes on some rare and interesting species, including the white wagtail, Pallas's grey shrike, waxwing, Cassin's snow-goose, garganey teal, red-necked phalarope, ruff, black tern; whilst the scarcity or entire absence of the tree sparrow, hooded crow, and brent goose, and the presence of the bernacle goose, are of interest to one accustomed to east-coast observations. The capture, too, of eight storm-petrels at the South Bishop, on October 14, is a noteworthy incident. The lanterns vary not a little in their death-dealing attractions, those of the Bardsey, South Bishop, Smalls, Nash (E), Godrevy, and Eddystone lighthouses being most seductive, occasionally commanding no less than two hundred victims in a single night.

From the Irish coasts it is reported that in 1884 the number of birds was equal to, and in a few instances above, the average.

The great bulk of migrants arrive on the southern half of the east coast of Ireland, and on the easternmost of the southern counties—in other words, along the shore extending from Dublin to Waterford, and having its limits at Rockabill Lighthouse and Dungarvan Lighthouse.

A *marked* migratory movement might be expected in the north-eastern counties between Scotland and Ireland, where the Irish Channel is narrowest; but we do not find such to be the case.

The usual course taken by birds seems to be either N.W. or S.E. The number of birds which only occur singly and do not seem to migrate in flocks is large. In such instances it is difficult to trace the line of migration.

The occurrences now noted of the Greenland falcon properly belong to the same flight that has already been noticed in last year's report.

As might be expected, the snow bunting is of more frequent occurrence on the western and northern coasts. A few remained as late as the first week in May, and it was again seen early in September, dates which have not hitherto been recorded in Ireland. Geese were also more numerous on the north and west coasts.

A remarkable migration of the rook was observed at the Tearaght and Skelligs, both stations being several miles off the coast of Kerry. It lasted for three weeks, from November 2 to 20, the direction of flight being from west to east. The light-keepers were puzzled to know whence the birds could have come, the nearest land to the west being America, in which this species is not found.

Mr. Gätke's Heligoland notes, from June 28 to the end of the year, comprise 118 species, including, as usual, several rare visitors to the ornithological observatory:—Icterine Warblers on Aug. 18; *Anthus richardi*, Sept. 3 to Oct. 12: *A. campestris*, Sept. 4; *Carpodacus erythrinus*, Sept. 9; *Anthus cervinus*, a great many, from Sept. 15 to Oct. 12; *Lanius major*, in most unusual numbers, from. Sept. 17 to Nov. 4; *Alauda cristata*, Sept. 30 and Oct. 1; *Saxicola stapazina* (?), Oct. 2; *Turdus varius*, Oct. 3, 12, and 23, one each day: *Emberiza pusilla*, Oct. 5, two; *Turdus migratorius*, one on Oct. 14; *Fringilla rufescens*, our English redpoll, one on Nov. 22. Besides these large numbers of continental species, which are classed amongst the rare and occasional visitants to the British Islands, and whose line of migration is normally far to eastward of these islands, as *Emberiza hortulana*, *Motacilla flava*, *M. alba*, *Cyanecula suecica*, *Anthus rupestris*, *Plectrophanes lapponicus*, *Otocorys alpestris*, *Nyctala tengmalmi*, *Ruticilla titys*, *Regulus ignicapillus*, and *Larus minutus*.

The great rush of birds crossed Heligoland during the last fortnight in October, and appears to have come directly across to our eastern shores. Mr. Gätke remarks, under date Oct. 24, S.E., clear, fine, early rather cold, *C. cornix*, *C. frugilegus*, and *C. monedula*, 'monstrous numbers;' *cornix* and *monedula* mixed in uninterrupted flights of ten and twelve minutes each, continued with but short interruptions or gaps; width as far as the eye could reach in northerly and southerly directions; and thus from 9 A.M. till 1 P.M. *Sturnus*, 'a succession of clouds sweeping past overhead.'

The Committee have again to thank Professor Chr. Fr. Lütken, of Copenhagen, for a list of the birds killed against the lighthouse of Stevns, on the projecting part of Zealand, marking the limit between the Baltic and Oresund.

In conclusion your Committee would take the opportunity of thanking the Master and Elder Brethren of the Trinity House, the Commissioners of Northern Lights, and the Commissioners of Irish Lights for their ready co-operation and assistance, through their intelligent officers and men, in the inquiry.

The Committee respectfully request their reappointment.

Report of the Committee, consisting of General Sir J. H. LEFROY, Lieut.-Colonel GODWIN-AUSTEN, Mr. W. T. BLANFORD, Mr. SCLATER, Mr. CARRUTHERS, Mr. THISELTON-DYER, Professor STRUTHERS, Mr. G. W. BLOXAM, Mr. H. W. BATES (*Secretary*), Lord ALFRED CHURCHILL, Mr. F. GALTON, and Professor MOSELEY, *appointed for the purpose of furthering the Exploration of New Guinea, by making a grant to Mr. Forbes for the purposes of his expedition.*

THE Committee beg leave to report that the grant of 200*l*. voted by the Association towards the expenses of Mr. H. O. Forbes' expedition was paid to Mr. Forbes on January 9 last, and that he sailed from England early in April. In a letter from Batavia, dated June 30, Mr. Forbes says that he arrived at that port on May 8, and that his time in the interval had been occupied in a journey to Amboyna and back, made for the purpose of securing the services of four hunters, whose abilities and fidelity had been tested on his former journeys in various islands of the Archipelago. The four hunters had been engaged, as also twenty native carriers, a number which it would be necessary to increase to twenty-five. He had arranged to leave Batavia in the steamer for Thursday Island, Torres Straits, about July 13, and hoped to reach that station on the 20th of the same month. At Thursday Island he would be joined by his assistant, Mr. Thiele, and would then decide whether he would make the southern coast of New Guinea, near Port Moresby, his starting point into the interior, or Dyke-Acland Bay on the north-eastern coast.

Report of the Committee, consisting of General Sir J. H. LEFROY, the Rev. Canon CARVER, Mr. F. GALTON, Mr. P. L. SCLATER, Professor MOSELEY, Dr. E. B. TYLOR, Professor BOYD DAWKINS, Mr. G. W. BLOXAM, and Mr. H. W. BATES (*Secretary*), *appointed for the purpose of furthering the scientific examination of the country in the vicinity of Mount Roraima in Guiana, by making a grant to Mr. Everard F. im Thurn for the purposes of his expedition.*

THE Committee beg leave to report that the sum of 100*l*. granted by the Association has been paid to Mr. Everard im Thurn, whose report, together with the map of the neighbourhood of the mountain from the surveys of Mr. H. J. Perkins, a member of Mr. im Thurn's expedition, was published in the number for August, 1885, of the 'Proceedings of the Royal Geographical Society,' who had contributed 200*l*. towards the cost of the expedition.

Report of the Committee, consisting of the Rev. Canon TRISTRAM, the Rev. F. LAWRENCE, *and* Mr. JAMES GLAISHER (*Secretary*), *appointed for the purpose of promoting the Survey of Palestine.*

THE Survey of Eastern Palestine has been carried on during the last year privately by Herr G. Schumacher, C.E., assisted by Mr. Laurence Oliphant, who has also furnished the Committee with valuable notes of personal exploration in the district now called Junlau—the ancient Gaulanitis. The portion surveyed by Herr Schumacher consists of about 200 square miles, and covers an area previously quite unknown. The map, which is now in the hands of the Committee, is accompanied by voluminous memoirs and a great number of sketches, drawings, and plans of ruins figured for the first time. These drawings are now in the hands of the engravers, and it is proposed to publish them, with the memoirs, in October. The map will be laid down on the sheet to which it belongs. It is hoped that Herr Schumacher may be able to continue working in this way for the Society, so that, though it may be found impossible to send, as before, a large and well equipped party of Royal Engineers to survey the country, we may yet be continuously working, always extending our map, and acquiring new knowledge of this little-visited district. As regards other portions of the Holy Land, the map of the Wady Arabah has been laid down in the Society's sheets; the geological memoirs compiled by Professor Hull after his expedition of 1883–1884 are nearly ready, and will be issued before the end of the year; and the Society has been enabled to secure Mr. Chichester Hart's Natural History memoir, made from new observations during the same journey. In addition to Mr. Laurence Oliphant's paper, the Committee have received from Mr. Guy le Strange, and published, observations and notes made by him during a recent journey east of Jordan. The results of the survey, so far as it has been completed, will appear in a map reduced to a scale of about three miles to an inch, showing the country on both sides of the river Jordan, instead of on the western side only. The Old and New Testament names, with tribe boundaries and later divisions, have also been prepared for this map, and will be printed upon it in colour. A list of ancient names with modern identifications has been prepared, and will be issued with it. This portion of the work is under the direction of Colonel Sir Charles Wilson, K.C.M.G., F.R.S. The Society has also issued during the last year a popular account, by Professor Hull, of his recent journey, called 'Mount Seir,' and reprints of Captain Conder's popular books 'Tent Work in Palestine,' and 'Heth and Moab.' Finally, the Committee have completed the issue of their great work, the 'Survey of Western Palestine,' with the last volumes of 'Jerusalem,' the 'Flora and Fauna,' and a portfolio of plates showing the excavations and their results.

Report of the Committee, consisting of Dr. J. H. GLADSTONE (*Secretary*), Mr. WILLIAM SHAEN, Mr. STEPHEN BOURNE, Miss LYDIA BECKER, Sir JOHN LUBBOCK, *Bart.*, Dr. H. W. CROSSKEY, Sir RICHARD TEMPLE, Sir HENRY E. ROSCOE, Mr. JAMES HEYWOOD, *and* Professor N. STORY MASKELYNE, *appointed for the purpose of continuing the inquiries relating to the teaching of Science in Elementary Schools.*

THE principal duty of your Committee is to watch the course of legislative action as far as it has any bearing on the teaching of science in elementary schools; and naturally the annual modifications of the Educational Code claim the first consideration. This year, however, these modifications have been exceedingly small, and there is but one which affects the teaching of science, and that only indirectly.

Drawing has been made a class subject in the schools, and is to take its place with English, geography, elementary science, history, and needlework (for girls). Grants may be earned for three of these subjects. If one only is taken, it still must be 'English.' If three of these are taken, one of them must be 'drawing'; but if two are taken, the choice of the second subject lies between any of those that come after 'English.' Hence the addition of drawing reduces the chance of either of the scientific class subjects (geography or elementary science) being taught in elementary schools.

The Revised Instructions to Her Majesty's Inspectors issued this year contain the following additional clauses on geography, which meet with your Committee's entire approval:—'Geographical teaching is sometimes too much restricted to the pointing out of places on a map, and to the enumeration of such details as the names of rivers, towns, capes, and political divisions. It is hardly necessary to say that geography, if taught to good purpose, includes also a description of the physical aspects of the countries, and seeks to establish some associations between the names of places and those historical, social, or industrial facts which alone make the names of places worth remembering. It is especially desirable in your examination of the Fourth and higher Standards, that attention should be called to the English colonies and their productions, government, and resources, and to those climatic and other conditions which render our distant possessions suitable fields for emigration, and for honourable enterprise.'

As to the effect of the regulations on the teaching of these class subjects, the annual return of the Education Department shows that the teaching of geography is actually diminishing in our schools, and that elementary science has scarcely gained a footing. The following table shows the position of affairs, the figures for 1882–3 being calculated on the basis that the departments examined in the last four months of that year were 31·1 per cent. of the whole:—

Class Subjects		1882–3	1883–4
Geography	Departments	12,823	12,775
Elementary Science	,,	48	51
History	,,	367	382
Needlework	,,	5,286	5,929
		18,524	19,137

In regard to the scientific specific subjects, the following are the numbers of children individually examined, the figures for the year 1882–3 being computed as before :—

Specific Subjects		1882–3	1883–4
Algebra . . .	Children	26,547	24,787
Euclid and Mensuration	,, ...	1,942	2,010
Mechanics, A. . . .	,, ...	2,042	3,174
,, B. . . .	,, ...	——	206
Animal Physiology .	,, ...	22,759	22,857
Botany	,, ...	3,280	2,604
Principles of Agriculture	,, ...	1,357	1,859
Chemistry	,, ...	1,183	1,047
Sound, Light, and Heat	,, ...	630	1,253
Magnetism and Electricity	,, ...	3,643	3,244
Domestic Economy .	,, ...	19,582	21,458
Extra (Physiography) .	,, ...	——	16
		82,965	84,515

It will be seen that a slight increase has taken place in the aggregate number, but this is not at all in proportion to the increase in the number of children presented in Standards V., VI., and VII.—viz. 286,355 in 1882–3, and 325,205 in 1883–4. Next year's return will indicate more clearly what changes are taking place in the popularity of the different subjects; but it would appear that botany is decreasing, while mechanics, sound, light, and heat, and the principles of agriculture are making a decided advance.

This increase in the study of mechanics is no doubt partly due to the peripatetic method of teaching this subject which has proved so successful in Liverpool and Birmingham. It has just been commenced in one district in London.

The Report of the Committee of Council on Education, which has just been issued, makes the following comments on the small extent to which science is taught in our elementary schools :—

'The wider range of class subjects allowed by the Code under the head of "Elementary Science" does not appear to be taken advantage of to any great extent at present.'

'As to specific subjects . . . only 20·49 per cent. of the scholars eligible for examination in a specific subject have been so examined.'

It also draws attention to the proportionate amount of the Government grant paid for instruction in the various subjects in the boys' and girls' schools (excluding infants). It would appear that, out of a total of 17*s.* $2\frac{1}{2}$*d.* per head, less than $1\frac{1}{4}$*d.* is for specific subjects, while $8\frac{1}{4}$*d.* is given for singing alone.

It should, however, be mentioned that a few more children are studying some branch of science in classes under the Science and Art Department in some of our best schools.

In regard to technical education, it will be remembered that at the Southport meeting a recommendation was passed that this Committee 'be requested to consider the desirableness of making representations to the Lords of the Committee of Her Majesty's Privy Council on Education in favour of aid being extended towards the fitting up of workshops

in connection with elementary day schools or evening classes, and of making grants on the results of practical instruction in such workshops under suitable direction, and, if necessary, to communicate with the Council.'

The Committee awaited the appearance of the second report of the Royal Commissioners on Technical Instruction, and at the meeting at Montreal merely expressed a thorough approval of the recommendations of the said Commissioners:—'That proficiency in the use of tools for working in wood and iron be paid for as a specific subject, arrangements being made for the work being done, so far as practicable, out of school hours. That special grants be made to schools in aid of collections of natural objects, casts, drawings, &c., suitable for school museums.'

Last February, however, your Committee reported to the Council that they did consider it desirable to make representations to the Education Department, and suggested that the encouragement for the teaching of handicraft might take the form of that recommended by the Royal Commissioners on Technical Instruction; or that 'the use of tools' in boys' schools might be placed in the same position as 'practical cookery' in girls' schools. The Council received the report, but did not see their way to proceed further in the matter.

In the meantime, a very interesting experiment is being made by the Birmingham Board at the Bridge Street Seventh Standard School. This is an attempt to add to the education given in the public elementary schools a practical training in the use of ordinary workshop tools and sound elementary instruction in those sciences and arts upon which the trades and manufactures of Birmingham are based, such as theoretical and practical mechanics, chemistry, electricity, model and machine drawing, and the principles of machinery. Although it is necessary to prepare for examinations by Her Majesty's Inspector under the Code, all the subjects are taught on lines which will have a practical and technical bearing. A two years' course of instruction has been arranged, the subjects taken being:—Arithmetic, algebra, Euclid, theoretical chemistry, practical chemistry, drawing (solid geometry, free-hand). In the second year electricity is added.

The London Board has just arranged an experiment for teaching the use of tools to a class of boys on Saturday mornings in the Carlton Road school. It is confined to working in wood, and follows the plans adopted in the Slöyd system, which is carried out to such a large extent in Sweden, and has been introduced into some other parts of the Continent. It is proposed also to try another experiment at Beethoven Street School, Kensal, with Seventh Standard boys. It will take more the form of practical carpentry.

Report of the Committee, consisting of Sir FREDERICK BRAMWELL (*Secretary*), Professor A. W. WILLIAMSON, Professor Sir WILLIAM THOMSON, Mr. ST. JOHN VINCENT DAY, Sir F. ABEL, Captain DOUGLAS GALTON, Mr. E. H. CARBUTT, Mr. MACRORY, Mr. H. TRUEMAN WOOD, Mr. W. H. BARLOW, Mr. A. T. ATCHISON, Sir R. E. WEBSTER, Mr. A. CARPMAEL, Sir JOHN LUBBOCK, Mr. THEODORE ASTON, *and* Mr. JAMES BRUNLEES, *appointed for the purpose of watching and reporting to the Council on Patent Legislation.*

ON August 14, 1885, an Act was passed entitled 'An Act to amend the Patents Designs and Trades Marks Act' of 1883.

This amending Act consists of six sections, the first and second of which relate to matters of form.

The third section deals with an extension of time which under certain circumstances might be allowed for the reception of the complete specification and for the sealing of the patent.

The fourth section is a very important one. It provides for that which the members of this Committee and the Committee of the Society of Arts desired to see introduced into the Act of 1883, viz., that where an application for a patent has not been perfected, the specification, with its drawings, if any, left in connection with the application, shall not at any time be open to public inspection or be published by the Comptroller.

In the view of the Committee this is a most salutary provision. As the law stood, the publication of crude and immature ideas, meaningless at the time, but to which a meaning might be given when success had been attained by some independent inventor, frequently prevented such inventor from obtaining a valid patent, to the great loss of the public as well as of himself.

In at length introducing this provision into the Patent Act, the Government has followed the plan pursued in the United States in respect of the document which, so far as its citizens are concerned, is the equivalent of our provisional specification.

The Committee regard this fourth section with great satisfaction, as showing that it is at last recognised to be for the benefit of the public not to throw open new inventions, but to give an inventor the strong personal interest which induces him to push his invention into practical work. In fact, the truth of the oft-quoted saying of the late Sir William Siemens, that 'if an invention were found lying in the gutter, it would be in the interest of the public to assign it to some person as owner,' is admitted.

Section 5 is also important as clearing up a doubt whether, under the Act of 1883, a patent could be lawfully granted to two or more persons, when some of the persons to whom it was granted had not had any part in the invention. Section 5 of this Act of 1885 declares that it has been, and is, lawful, under the Act of 1883, to grant a patent under such circumstances.

The sixth and last section relates to a slight, but not unimportant, alteration in section 103 of the Act of 1883. This section (section 103) has not yet attracted as much public attention as its importance demands. Many of the Governments of Europe, including Great Britain, have entered into a Convention by which they are endeavouring to introduce an International Patent Law. It has been officially announced that England

has complied with all necessary formalities, so that it is to be assumed that this law is already in force. Its effect will not be inconsiderable: as the date of applying for a patent in any country of the Union fixes the time from which the applicant may be entitled to a patent in all the other countries, even though he may not apply in the other countries for a considerable time after having made application in his own, and even though others may have applied in the meantime. Section 103 of the 1883 Act provided in effect that if Her Majesty became a party to the Convention, an applicant from any of the States of the Union should be entitled to an English patent in priority to other applicants, and that his patent should have the same date as the date of the protection obtained in such foreign State. The amendment made by the sixth section of the Amending Act is to change the words 'date of the *protection*' which occur in section 103 of the Principal Act, into 'date of the *application*,' which seems to be more in accordance with the terms of the Convention.

The Committee desire to be reappointed, in order to be in a position to watch the working of the Principal Act, of this Supplementary Act, and of the International Convention, and to report upon any amendments that may be proposed in any of them.

The Committee would be glad for the grant of 5*l.* for expenses to be renewed.

Report of the Committee, consisting of Dr. E. B. Tylor, Dr. G. M. Dawson, General Sir J. H. Lefroy, Dr. Daniel Wilson, Mr. Horatio Hale, Mr. R. G. Haliburton, *and* Mr. George W. Bloxam (*Secretary*), *appointed for the purpose of investigating and publishing reports on the physical characters, languages, industrial and social condition of the North-western Tribes of the Dominion of Canada.*

The Committee have been in active correspondence with missionaries and others stationed among the Indians, but the unsettled state of the country during the past year has made it impossible to do more than collect materials for a preliminary report; the Committee, therefore, ask that they may be reappointed, with a continuance of the grant.

Report on the Blackfoot Tribes. Drawn up by Mr. Horatio Hale.

The tribes composing the Blackfoot Confederacy, as it is commonly styled—in some respects the most important and interesting Indian communities of the North-west—have been until recently less known than any others. It seemed, therefore, that the best contribution which a single member could make to the general report of the Committee would be a special study of these tribes. This view was confirmed by the opinion of President Wilson, the only other member of the Committee who was near enough for me to consult with. With his aid a correspondence was opened with two able and zealous missionaries residing among these Indians, both of whom have replied most courteously and liberally to my inquiries. These are the Rev. Albert Lacombe, widely and favourably known as Father Lacombe, Roman Catholic Missionary among the Siksika, or proper Blackfeet Indians, and the Rev. John McLean, Missionary of the Canadian Methodist Church to the Blood and

Piegan (or Kena and Piekanè) tribes. Father Lacombe has been many years a missionary in the Canadian North-west, and has a very extensive knowledge of the tribes of that region. His elaborate work, the 'Grammar and Dictionary of the Cree Language,' ranks among the best contributions to American philology. Mr. McLean has been engaged in his missionary duties for five years, has prepared a grammar of the Blackfoot language, and is at present occupied in translating the Scriptures into that tongue; he has been most considerate in furnishing the information which was requested on behalf of the Committee, and is now making special researches for this object.

The unfortunate troubles of the past season have for a time interrupted the correspondence, and have left the investigations necessarily incomplete. The principal portion of the report on these Indians will therefore have to be deferred for another year. It has seemed advisable, however, to submit a summary of the knowledge now obtained by way of introduction to the fuller account which the Committee may be able to render hereafter. With this view some other sources of information have been examined, particularly the valuable official reports and maps of the Canadian and United States Indian Departments, which have been obligingly furnished by those Departments for this purpose.

Fifty years ago the Blackfoot Confederacy held among the western tribes much the same position of superiority which was held two centuries ago by the Iroquois Confederacy (then known as the 'Five Nations') among the Indians east of the Mississippi. The tribes of the former confederacy were also, when first known, five in number. The nucleus, or main body, was—as it still is—composed of three tribes, speaking the proper Blackfoot language. These are the Siksika, or Blackfeet proper, the Kena, or Blood Indians, and the Piekanè, or Piegans (pronounced Peegans), a name sometimes corrupted to 'Pagan' Indians. To these are to be added two other tribes, who joined the original confederacy, or, perhaps more properly speaking, came under its protection. These were the Sarcees from the north, and the Atsinas from the south. The Sarcees are an offshoot of the great Athabascan stock, which is spread over the north of British America, in contact with the Eskimo, and extends in scattered bands—the Umpquas, Apaches, and others—through Oregon and California into Northern Mexico. The Atsinas, who have been variously known from the reports of Indian traders as Fall Indians, Rapid Indians, and Gros Ventres, speak a dialect similar to that of the Arapohoes, who now reside in the 'Indian Territory' of the United States. It is a peculiarly harsh and difficult language, and is said to be spoken only by those two tribes. None of the Atsinas are now found on Canadian territory, and no recent information has been obtained concerning them, except from the map which accompanies the United States Indian Report for 1884, and on which their name appears on the American Blackfoot Reservation.

The five tribes were reckoned fifty years ago to comprise not less than thirty thousand souls. Their numbers, union, and warlike spirit made them the terror of all the western Indians on both sides of the Rocky Mountains. It was not uncommon for thirty or forty war parties to be out at once against the Salish (or Flatheads) of Oregon, the Upsarokas (or Crows) of the Missouri plains, the Shoshonees of the far south, and the Crees of the north and east. The country which the Blackfoot tribes claimed properly as their own comprised the valleys and plains

along the eastern slope of the Rocky Mountains, between the Missouri and the Saskatchewan. This region was the favourite resort of the buffalo, whose vast herds afforded the Indians their principal means of subsistence. In the year 1836 a terrible visitation of the small-pox swept off two-thirds of the people, and five years later they were supposed to count not more than fifteen hundred tents, or about ten thousand souls. Their enemies were then recovering their spirits, and retaliating upon the weakened tribes the ravages which they had formerly committed.

In 1855 the United States Government humanely interfered to bring about a complete cessation of hostilities between the Blackfoot tribes and the other Indians. The Commissioners appointed for the purpose summoned the hostile tribes together, and framed a treaty for them, accompanying the act by a large distribution of presents. This judicious proceeding proved effectual. Dr. F. V. Hayden in his account of the Indian Tribes of the Missouri Valley (published in the 'Transactions of the American Philosophical Society for 1862'), states that from the period of this treaty the Blackfoot tribes had become more and more peaceful in their habits, and were considered, when he wrote, the best disposed Indians in the North-west. He remarks that their earlier reputation for ferocity was doubtless derived from their enemies, who always gave them ample cause for attacking them. He adds: 'From my own experience among them, and from information derived from intelligent men who have spent the greater portion of their lives with them, I am convinced that they are among the most peaceable and honourable Indians in the West; and in an intellectual and moral point of view they take the highest rank among the wild tribes of the plains.'

This favourable opinion of Dr. Hayden, it may be added, is entirely in accordance with the testimony of the Indian agents and other officials of the Canadian North-west, who place the Blackfeet decidedly above the surrounding tribes in point of intelligence and honesty. At the present time, while constantly harassed on their reserves by the incursions of thievish Crees and other Indians, who rob them of their horses, they forbear to retaliate, and honourably abide by the terms of their treaty, which binds them to leave the redress of such grievances to the Dominion authorities. It has seemed proper to dwell upon this point, as the marked differences of character among the Indian tribes has been too little regarded. As a question of science and a matter of public policy, these differences deserve a careful study. The good disposition manifested by the Blackfoot tribes during the recent disturbances has displayed their natural character, and has been a fact of the utmost value to the welfare of the new settlements.

Since the general peace was established by the American Government the numbers of the Blackfeet have apparently been on the increase. Dr. Hayden reports the three proper Blackfeet tribes as numbering in 1855 about 7,000 souls. The present population of the three Canadian Reserves is computed at about 6,000, divided as follows: Blackfeet proper, 2,400; Bloods, 2,800; Piegans, 800. On the American Reservation there are stated to be about 2,300, mostly Piegans. This would make the total population of the three tribes exceed 8,000 souls. The adopted tribe, the Sarcees, have greatly diminished in numbers through the ravages of the small-pox. In 1870 this disease raged among them with great virulence. They were then residing on the American side, in Montana. Mr. McLean writes: 'An eye-witness told me that at the

Maria's River, in Montana, there stood fully one hundred lodges, and not one contained less than ten bodies. His estimate of dead Sarcees was 1,500.' This tribe, now numbering less than 500 souls, have their Reserve near Calgary. They are reputed to be less cleanly and moral than the proper Blackfeet tribes. In this respect their habits and character correspond with those of other Athabascan tribes.

During the past five years, as is well known, a great change has taken place in the condition of the north-western tribes through the extermination of the buffalo. The transcontinental railways have brought into the interior great numbers of hunters, armed with the most destructive weapons, who have engaged in a constant and reckless slaughter of these animals, until it is now doubtful if any are left alive. The Blackfeet have been the greatest sufferers from this cause. The buffalo were their main dependence. The animals, which roamed the plains during the summer, were accustomed to resort to the sheltered and wooded valleys of the Blackfoot country during the winter; and thus the tribes were assured of a supply of food at all seasons. The skins furnished their clothing, their tents, and their couches. Suddenly, almost without warning, they found themselves stripped of nearly every necessary of life. The change was one of the greatest that could well befall a community. If the inhabitants of an English parish were suddenly transported to the centre of Australia, and set down there, utterly destitute, to make a living by some unknown methods of tropical agriculture, they would hardly be more helpless and bewildered than these unfortunate Indians found themselves. The Governments both of the United States and of Canada came to the rescue; but in the former country the urgency of the case was not at first fully understood, and much suffering ensued. The agent on the Blackfoot Reservation in Montana (Major Allen) states in his official report that when he entered upon his duties in April 1884 he found the Indians in a deplorable condition. The supplies of food which had been sent for them had proved insufficient, and before these could be renewed many died from actual starvation. Some stripped the bark from the saplings which grew along their creeks, and ate the inner portion to stifle the sense of hunger. On the Canadian side, fortunately, the emergency was better understood. Colonel McLeod, an able and vigilant officer, was in charge of the Mounted Police at that time, and through his forethought the necessary preparations were made. In 1879 and 1880 the buffalo disappeared from that region. Arrangements were at once made for settling the Indians on Reserves, and for supplying them with food and clothing, and teaching them to erect wooden houses and cultivate their lands. Daily rations of meat and flour were served out to them. Ploughs, cattle, and horses were furnished to them. Farm instructors were placed among them. The Indians displayed a remarkable readiness to adapt themselves to the new conditions. According to the reports of all the agents they have evinced a quickness to learn and a persevering industry which place them decidedly in advance of the other Indian tribes of that region. In 1882 more than 500,000 lbs. of potatoes were raised by the three Blackfoot tribes, besides considerable quantities of oats, barley, and turnips. The Piegans had sold 1,000 dollars' worth of potatoes, and had a large supply on hand. 'The manner in which the Indians have worked,' writes the agent, 'is really astonishing, as is the interest they have taken, and are taking, in farming.' Axes and other tools were distributed among them,

and were put to good use. In November 1882 the agent writes that log-houses had 'gone up thick and fast on the Reserves, and were most creditable to the builders.' In many cases the logs were hewn, and in nearly all the houses fireplaces were built. In the same year another official—the Indian Commissioner—going through the Reserves, was surprised at the progress which he saw. He found comfortable dwellings, well-cultivated gardens, and good supplies of potatoes in root-houses. Most of the families had cooking stoves, for which they had sometimes paid as much as fifty dollars. He 'saw many signs of civilisation, such as cups and saucers, knives and forks, coal-oil lamps, and tables; and several of the women were baking excellent bread and performing other cooking operations.' Three years before these Indians were wild nomads, who lived in skin tents, hunted the buffalo, and had probably never seen a plough or an axe. These facts are recorded, not merely as gratifying to a sense of humanity, but for their bearing on the question of the natural capacity of uncivilised men. Impartial investigation and comparison will probably show that, while some of the aboriginal communities of the American continent are low in the scale of intellect, others are equal in natural capacity, and possibly superior, to the highest of the Indo-European nations. The fundamental importance of this fact (if such it is) to the science of anthropology must be the excuse for urging its consideration in connection with the present inquiry.

The Blackfeet have been known to the whites for about a century, and during that period have dwelt in or near their present abode. There is evidence, however, that they once lived further east than at present. The explorer Mackenzie, in 1789, found them holding the south branch of the Saskatchewan, from its source to its junction with the north branch. He speaks of four tribes—the Picaneux, Blood, and Blackfeet, and the Fall Indians (Atsinas), which latter tribe then numbered about 700 warriors. Of the three former tribes he says: 'They are a distinct people, speak a language of their own, and, I have reason to think, are travelling north-west, as well as the others just mentioned (the Atsinas); nor have I heard of any Indians with whose language that which they speak has any affinity.'

The result of Mr. McLean's inquiries confirms this opinion of the westward movement of these Indians in comparatively recent times. 'The former home of these people,' he writes, 'was in the Red River country, where, from the nature of the soil which blackened their moccasins, they were called Blackfeet.' This, it should be stated, is the exact meaning of *Siksika*, from *siksinam*, black; and *ka*, the root of *oqkatsh*, foot. The meaning of the other tribal names, *Kena* and *Piekanè*, is unknown. That they were once significant cannot be doubted, but the natives are now unable to explain them, and use them merely as appellatives.

The westward movement of the Blackfeet has probably been due to the pressure of the Crees upon them. The Crees, according to their own tradition, originally dwelt far east of the Red River, in Labrador and about Hudson's Bay. They have gradually advanced westward to the inviting plains along the Red River and the Saskatchewan, pushing the prior occupants before them by the sheer force of numbers. This will explain the deadly hostility which has always existed between the Crees and the Blackfeet.

It will seem, at first view, a perplexing circumstance that M. Lacombe, who, of all authorities, should be the best informed on this subject, and

who has himself recorded this westward movement of the Crees, is disposed to question the fact of the corresponding movement of the Blackfeet. In his last letter, in reply to my inquiries, he expresses a doubt as to their former sojourn in the Red River region, and adds : 'They affirm, on the contrary, that they came from the south-west, across the mountains—that is, from the direction of Oregon and Washington Territory. There were' (he adds) 'bloody contests between the Blackfeet and the Nez-percés, as Bancroft relates, for the right of hunting on the eastern slope of the Rocky Mountains.' Mr. McLean, who mentions the former residence of the Blackfeet in the Red River country as an undoubted fact, also says in the same letter, 'It is supposed that the great ancestor of the Blackfeet came across the mountains.'

Here are two distinct and apparently conflicting traditions, each having good authority and evidence in its favour. One of the best tests of the truth of tradition is to be found in language. Applying this test in the present instance, we are led to some interesting conclusions. It has been seen that Mackenzie, to whom we owe our first knowledge of the Blackfoot tribes, declared that their language had no affinity with that of any other Indians whom he knew of. He was well acquainted with the Crees and Ojibways, who speak dialects of the great Algonkin stock, but he recognised no connection between their speech and that of the Blackfeet. Another traveller (Umfreville), whose book was published in 1791, gave a list of forty-four words of the Blackfoot language. The distinguished philologist Albert Gallatin, whose great work, the 'Synopsis of the Indian Tribes' (which still remains the best authority on North American philology), appeared in 1836, examined this list of Umfreville, and pronounced it sufficient to show that the language of the Blackfeet was 'different from any other known to us.' A few years later he received from an Indian trader a more extended vocabulary, and he then, in a second memoir on the subject, corrected his former statement, and showed that there was a clear affinity between the Blackfoot speech and the language of the Algonkin family. More recently the French missionaries made the same discovery, which seems to have been to them equally unexpected. M. Lacombe writes to me: 'The Blackfoot language, although far from, belongs to the same family as the Algic, Ojibway, Sauteux, Maskegon, and Cree. We discovered this analogy by studying the grammatical rules of these languages.'

Here will be noticed the rather remarkable fact that some of the ablest and most experienced of North American linguists have at first supposed the Blackfoot language to be distinct from all others, and have only discovered its connection with the Algonkin family by careful study. M. Lacombe has been good enough to send me a pretty extensive vocabulary of Blackfoot words, compared with the corresponding words in the Cree and Ojibway languages. He has added what, for the purpose in view, is equally important—many paradigms of grammatical forms in the Blackfoot, compared with similar forms in the Cree and Ojibway tongues. The Blackfoot language is thus shown to be, in its grammar, purely Algonkin. The resemblance is complete in the minutest forms, and in examining these alone it would seem incomprehensible that any doubt of the connection of this language with that stock could have been entertained. But when we turn to the vocabulary, by which the first judgment of a language is necessarily formed, the origin of the early error becomes apparent. Many of the most common words are totally different

from the corresponding words in the Algonkin languages. Others, which are found on careful examination to be radically the same as the corresponding Algonkin terms, are yet so changed and distorted that the resemblance is not at first apparent. Of this variation and distortion the numerals afford a good example. It should be mentioned that in the Indian words which follow, the vowels are to be pronounced as in Italian or German, and the consonants generally as in English. The only peculiarities are in the *j*, which has the French sound (like *z* in *azure*), and the *q*, which I have employed to express a sound resembling the German guttural *ch*, as heard in *lachen*. Mr. McLean writes this sound with *ch*, as in German, and M. Lacombe with *r*. It seems to be a trilled guttural, approaching the sound which French philologists designate as the *r* grasseyé.

	Blackfoot	Cree	Ojibway
One	nitokiskam	peyak	pejik
two	natokam	nijo	nij
three	newowiskam	nisto	nisswi
four	nijoim	newo	niwin
five	nijitji	niyanan	nanan
six	nawo	ningotwasik	ningotwasswi
seven	ikitchike	tepakoup	nijwasswi
eight	nanisho	ayenanew	nishwasswi
nine	pikkiso	kekamitatat	jangasswi
ten	kepo	mitatat	mitaswi
twenty	najippo	nijtano	nijtana
thirty	neppo	nistomitano	nissimitana
one hundred	kepippo	mitatato-mitano	ningotwak

Other words in ordinary use will show the total unlikeness in some cases, and the distorted resemblance in others:—

	Blackfoot	Cree	Ojibway
God	omakkatose	kije-manito	kije-manito
heaven	spoutch	kitchi kijik	kitchi kijik
day	kristikoy	kijikaw	kijikat
night	kokoy	tibiskaw	tibikkat
man	matapi	ayisiyiniw	anisinabe
woman	akew	iskwew	ikkwe
boy	saqkomapi	napesis	kwiwisens
girl	akekowan	iskwesis	ikkwesens
sun	natous	pisim	gisis
earth	tchaqkoum	askiy	akki
water	oqki	nipiy	nipi
fire	tchi	iskoutew	iskoutew
river	niyetaqkay	sipiy	sipi
lake	omaxikimi	sakahigan	sakahigan
house	napi-oyis	waskahigan	wakkahigan
knife	stowan	mokkouman	mokkouman
kettle	iska	askik	akik
tree	mistis	mistek	mittik
my father	n'inna	n'ottawiy	n'oss
my mother	nikrista	ningawiy	ninge
my son	n'oqkowa	nikosis	nigwis
my daughter	nit'ana	nit'anis	nind'anis
my head	n'otokan	n'istikwan	n'istigwan
my mouth	n'ahoy	n'int-on	nind-on
my teeth	n'orpikisth	nipita	nipita
my skin	n'otokis	n'asakay	ninjagai
my tongue	n'atchini	nit'eyaniy	nin'tenani
my heart	n'oskitchipappi	ni-teh	ni-teh
my blood	n'ahaban	ni-mik	ni-mik
my leg	n'oqkat	n'iskat	nikat

No one who examines this list will wonder that the connection between the Blackfoot and the other Algonkin tongues was not apparent to those who had to judge from brief and rude vocabularies of the former language. But it will be noticed that the possessive pronoun 'my' is evidently expressed by the same prefix *ni* (or *n'*) in all three languages. Pursuing this trace we compare the personal pronouns, and find a close resemblance, the difference being mainly in the terminations:—

	Blackfoot	Cree	Ojibway
I	nistowa	niya	nin
thou	kistowa	kiya	kin
he	oustoye	wiya	win
we	nistoninan	niyanan	ninawind
ye	kistowawa	kiyawa	kinawa
they	oustowawa	wiyawa	winawa

In the possessive prefixes the resemblance is still more notable. Thus in the Blackfoot language *n'otas* means 'my horse, or dog' (the same word, oddly enough, applying in this form to both animals); and in Cree *n't'em* has the same meaning. These words are thus varied with the possessive pronouns and in the two numbers:—

	Blackfoot	Cree
My horse (or dog)	n'otas	n't'em
thy " "	k'otas	kit'em
his " "	otas	otema
our " "	n'otasinan	n't'eminan
your " "	k'otasinan	kitemiwaw
their " "	otasiwaw	otemiwawa
my horses (or dogs)	n'otasiks	n't'emak
thy " "	k'otasiks	kit'emak
his " "	otasiks	otema
our " "	notasinaniks	n't'eminanak
your " "	kotasiwaweks	kitemiwawok
their " "	otasiwaweks	otemiwawa

So we may compare *n'inna*, my father, in Blackfoot, with *n'oss*, my father, in Ojibway.

	Blackfoot	Ojibway
My father	n'inna	n'oss
thy "	k'inna	k'oss
his "	ounni	ossan
our "	n'innan	n'ossinan
your "	kinnawaw	k'ossiwa
their "	onniwaw	ossiwan
my fathers	n'innaeks	nossag
thy "	k'innaeks	kossag
his "	ounnieks	ossan
our "	n'innaniks	n'ossinanig
your "	kinnaweks	k'ossiwag
their "	ounniwaweks	ossiwan

It will be seen that the close resemblance in grammar is as striking as the wide difference in the vocabulary. These facts admit of but one explanation. They are the precise phenomena to which we are accustomed in the case of mixed languages. In such languages—of which our English speech is a notable example—we expect the grammar to be derived entirely from one source, while the words will be drawn from two or more. Furthermore, wherever we find a mixed language we infer a conquest of one people by another. In the present instance we may well suppose that when the Blackfoot tribes were forced westward from the

Red River country to the foot of the Rocky Mountains, they did not find their new abode uninhabited. It is probable enough that the people whom they found in possession had come through the passes from the country west of those mountains. If these people were overcome by the Blackfeet, and their women taken as wives by the conquerors, two results would be likely to follow. In the first place, the language would become a mixed speech, in grammar purely Algonkin, but in the vocabulary largely recruited from the speech of the conquered tribe. A change in the character of the amalgamated people would also take place. The result of this change might be better inferred if we knew the characteristics of both the constituent races. But it may be said that a frequent, if not a general, result of such a mixture of races is the production of a people of superior intelligence and force of character.

The circumstances thus suggested may account, not only for the peculiarities of the language and character of the Blackfeet tribes, but also for the different traditions which are found among them in regard to their origin and former abode. It would be very desirable to trace that portion of the Blackfoot vocabulary which is not of Algonkin origin to its source in the language of some other linguistic stock. To do this would require a careful comparison of this foreign element with the various languages spoken in their vicinity, and particularly with those of the tribes west of the Rocky Mountains. For such a comparison there has been neither time nor adequate material, and this interesting subject of inquiry must be left for another occasion.

The religion of these tribes (applying this term to their combined mythology and worship) resembles their language. It is in the main Algonkin, but includes some beliefs and ceremonies derived from some other source. Father Lacombe's account of their cosmogony and their deities cannot be better given than in his own clear and pithy style. In their view, as in that of the Lenape and other Algonkin nations, there were two creations: the primary, which called the world into existence, and of which they have but a vague idea; and the secondary, which found the world an expanse of sea and sky (with, it would seem, a few animals disporting themselves therein), and left it in its present state. 'The primitive creation,' writes M. Lacombe, 'is attributed to a superior divinity, whom they call the Creator (*Apistotokiw*). This divinity, however, is in some manner identified with the sun (*Natōs*). The earth itself is believed to be a divinity of some kind, for, in their invocations, if they call the sun "our father" (*Kinnon*), they call the earth "our mother" (*Kikristonnon*). It seems also that the moon is considered to be one and the same divinity with the sun. At any rate, in the invocations it is designated by the same name, *Natōs*. Yet it is often said to be the "old woman," the consort of the sun. The whole of this is confused enough in the minds of the Indians to render them unable to give, when questioned, exact explanations.

'As to the secondary creation, if it may be so styled, the Indian account runs as follows: At a certain time it happened that all the earth was covered with water. The "Old Man" (*Napiw*) was in a canoe, and he thought of causing the earth to come up from the abyss. To put his project into execution he used the aid of four animals—the duck, the otter, the badger, and the musk-rat. The musk-rat proved to be the best diver. He remained so long under water that when he came to the surface he was fainting, but he had succeeded in getting a little particle of earth, which he brought between the toes of his paw. This particle of earth

the "Old Man" took, and blowing on it he swelled it to such an extent as to make the whole earth of it. Then it took him four days to complete his work, and make the mountains, rivers, plants, and beasts. (This number *four* is a fatidical one in the legends of these Indians.) The "Old Man" worked two days more in order to make the first woman, for after the first day's work he had not succeeded in making anything graceful. When the first woman, after much toil, was completed, a sort of council was held, in which the woman opposed every one of Napiw's propositions that would have been very favourable to the welfare of mankind. So we must conclude that all the evil on the earth comes from the woman's contradictious will.'

This Napiw, or 'Old Man,' adds Father Lacombe, 'appears again in many other traditions and legendary accounts, in which he is associated with the various kinds of animals, speaking to them, making use of them, and especially cheating them, and playing every kind of trick. In these legends Napiw comes down from the high position of creator to a much lower one, and appears not unlike to a buffoon and treacherous rascal. I will mention only that, according to the account of the Indians, the "Old Man" is said to have come from the south-west, across the mountains; and after a prolonged sojourn in these countries he went toward the north-east, where he disappeared, and nobody has heard of him since. The Indians point out the place where the "Old Man" played with the Coutonay Indians, not far from the Porcupine Hills; on another spot he slept; and on a hill not far from Red-deer River any one can see at the present day the place where Napiw came down by sliding.'

Those who have read Schoolcraft's 'Algic Researches,' Mr. Leland's 'Algonquin Legends,' and, above all, Dr. Brinton's 'Myths of the New World,' will recognise in Napiw the most genuine and characteristic of all the Algonkin divinities. In every tribe of this widespread family, from Nova Scotia to Virginia, and from the Delaware to the Rocky Mountains, he reappears under various names—Manabosho, Michabo, Wetuks, Glooskap, Wisaketjak, Napiw—but everywhere with the same traits and the same history. He is at once a creator, a defender, a teacher, and at the same time a conqueror, a robber, and a deceiver. But the robbery and deceit, it would seem, are usually for some good purpose. He preserves mankind from their enemies, and uses the arts and craft of these enemies to subdue and destroy them. In Dr. Brinton's view, his origin is to be found in a nature-myth, representing, 'on the one hand, the unceasing struggle of day with night, of light with darkness, and, on the other, that no less important conflict which is ever waging between the storm and sunshine, the winter and summer, the rain and clear sky.'

Napiw, the 'old man,' has, it seems, other names in the Blackfoot tongue. He is known as *Kenakakatsis*, 'he who wears a wolfskin robe,' and *Mik-orkayew*, 'he who wears a red-painted buffalo-robe.' These names have probably some reference to legends of which he is the hero. The name of the creator, *Apistotokiw*, as explained by M. Lacombe, offers a good example of the subtle grammatical distinctions which abound in the Siksika (or Blackfoot) speech, as in the other Algonkin tongues. The expression 'he makes,' or 'he creates' (which, like other verbal forms, may be used as a noun), can be rendered in four different forms. *Apistototsim* signifies 'he makes,' when the complement, or thing made, is expressed, and is an inanimate object. *Apistotoyew* is used when the expressed object is animate. *Apistotakiw* is the indefinite form, used

when the complement, or thing made, is not expressed, but is understood to be inanimate; and, finally, *Apistotokiw*, the word in question, is employed when the unexpressed object is supposed to be animate. The world, therefore, as first created, was, in the view of the Blackfoot cosmologist, an animated existence.

But while these beliefs are all purely Algonkin, the chief religious ceremony of the Blackfoot tribes is certainly of foreign origin. This is the famous 'sun-dance,' to which they, like the Dakota tribes and some of the western Crees, are fanatically devoted. That this ceremony is not properly Algonkin is clearly shown by the fact that among the tribes of that stock, with the sole exception of the Blackfeet and a few of the western Crees, it is unknown. Neither the Ojibways of the lakes nor any of the numerous tribes east of the Mississippi had in their worship a trace of this extraordinary rite. The late esteemed missionary among the Dakotas, the Rev. Stephen R. Riggs (author of the 'Dakota Grammar and Dictionary') says of this ceremony: 'The highest form of sacrifice is *self-immolation*. It exists in the "sun-dance," and in what is called "vision-seeking." Some, passing a knife under the muscles of the breast and arms, attach cords thereto, which are fastened at the other end to the top of a tall pole, raised for the purpose; and thus they hang suspended only by those cords, without food or drink, for two, three, or four days, gazing upon vacancy, their minds intently fixed upon the object in which they wish to be assisted by the deity, and waiting for a vision from above. Others, making incisions in the back, have attached, by hair-ropes, one or more buffalo-heads, so that every time the body moves in the dance a jerk is given to the buffalo-heads behind. This rite exists at present among the western bands of the Dakotas in the greatest degree of barbarity. After making the cuttings in the arms, breast, or back, wooden setons—sticks about the size of a lead-pencil—are inserted, and the ropes are attached to them. Then, swinging on the ropes, they pull until the setons are pulled out with the flesh and tendons; or, if hung with the buffalo-heads, the pulling-out is done in the dance by the jerking motion, keeping time with the music, while the head and body, in an attitude of supplication, face the sun, and the eye is unflinchingly fixed upon it.'

My correspondent, the Rev. Mr. McLean, sends me a minute and graphic account of this ceremony as he witnessed it, in June last, on one of the Blackfoot Reserves, when most of the Kena, or Blood Indians, were present as actors or spectators. His narrative is too long for insertion here in full, but the concluding portion will show the resolute constancy with which this sacrifice of self-immolation is performed—some new features being added, which are not found in the brief account of Mr. Riggs, though they may possibly belong also to the Dakota ceremony.

'This year several persons, young and old, who had made vows during times of sickness or danger, had a finger cut off by the first joint, as an offering to the sun; and others had the operation of cutting their breasts and backs. The old woman who cut the fingers off held the suppliant's hand up to the sun, and prayed; then placed it upon a pole on the ground, laid a knife on the finger, and with a blow from a deer's-horn scraper severed the member. The severed piece was taken up, held toward the sun, and the prayer made, when it was dropped into a bag containing similar members. This ceremony was gone through by each in turn. After this was done each carried an offering, and,

climbing the sacrificial pole with the face reverently turned toward the sun, placed the offering on the top of the pole. This year seven or eight persons went through the above ceremony. The other sacrificial ceremony consisted of the slitting of the flesh in two pieces in each breast. A wooden skewer was placed through each breast; a rope fastened to the sacrificial pole was placed around each skewer; and then the suppliant, whistling upon the bone-whistle, jumped about until the flesh gave way. In some instances the flesh was cut so deeply that the men had to press heavily upon the performers' shoulders in order to tear it away. The "shield ceremony" was the same process, only performed on the back, and the rope with a shield attached fastened to the skewers, and the ceremony continued until the suppliant was relieved.'

Mr. Riggs, it will be noticed, says that the ceremony was most zealously performed among the most westerly of the Dakota tribes, that is, those which are nearest to the Rocky Mountains. We are thus led to suppose that it may have had its origin among the tribes west of the mountains. Possibly the Blackfeet may have learned it from the tribe from which they acquired the foreign element of their language, and they may have taught it to the western Dakotas and Crees in their neighbourhood. In any case it is clear that they have a mixed religion, as well as a mixed language—which are both facts of considerable interest in ethnological science.

The form of government among the Blackfeet, as among the Algonkin tribes generally, is exceedingly simple, offering a striking contrast to the elaborately complicated systems common among the nations of the Iroquois stock. Each tribe has a head-chief, and each band of which the tribe is composed has its subordinate chief; but the authority of these chiefs is little more than nominal. The office is not hereditary. The bravest or richest are commonly chosen; but in what manner the election is made is not stated. Formerly the principal function of the head-chief consisted in deciding on the question of peace or war. At present it is limited to fixing the place of the camp, or directing a change of encampment. He presides in the council of his tribe, and is, in a conference with other nations, the representative and spokesman of his people.

The term 'confederacy' commonly applied to the union of the Blackfoot tribes is somewhat misleading. There is no regular league or constitution binding them together. 'The tribes are separate,' writes Mr. McLean, 'and the bonds of union are the unity of religious belief, social customs, and language. They united against a common enemy, but I have never heard of their fighting against each other.' Father Lacombe's account is similar. 'The Blackfeet,' he writes, 'have no league or confederation, properly so called, with councils and periodical reunions. They consider themselves as forming one family, whose three branches or bands are descended from three brothers. This bond of kinship is sufficient to preserve a good understanding among them.' They can hardly be said to have a general name for the whole community, though they sometimes speak of themselves as *Sawketakix*, or 'men of the plains,' and occasionally as *Netsepoyè*, 'or people who speak one language.'

Whether the system of clans, gentes, or totems, as they are variously styled by different writers, is found among the Blackfoot tribes is uncertain, the replies to inquiries on that subject being thus far somewhat indefinite. This system is regarded by some eminent ethnologists

as one of general prevalence, marking a certain stage in the progress of society. Others consider it to be merely a special and local manifestation of the associative impulse, frequently important, but by no means universal or essential in any stage. The fact that, while it prevails among the Iroquois, the Dakotas, and the Ojibways, it is not found among the Crees or the tribes of Oregon, seems to lend countenance to this view, and gives, at all events, particular interest to the inquiry in the present case. This and other questions remain for future investigation. For the reasons which have been stated, the present report is unavoidably imperfect. It is offered chiefly for the purpose of preserving the information which has already been obtained from sources of the highest authority, and of thus affording a trustworthy basis for further inquiry.

Report to the Council of the Corresponding Societies Committee, consisting of Mr. FRANCIS GALTON (*Chairman*), Professor A. W. WILLIAMSON, Captain DOUGLAS GALTON, Professor BOYD DAWKINS, Sir RAWSON RAWSON, Dr. GARSON, Dr. J. EVANS, Mr. J. HOPKINSON, Professor MELDOLA (*Secretary*), Mr. WHITAKER, Mr. G. J. SYMONS, *and* Mr. H. GEORGE FORDHAM.

THE Corresponding Societies Committee beg to report that they have received and considered applications from fifty-two Societies, and they recommend that those of the thirty-nine whose names are entered in the accompanying list be granted.

The Committee in making their selection have interpreted the phrase 'local scientific investigation,' which occurs in the new Rules (see Report 1884, pp. lxv. and lxvi.), according to the tenor of the examples they gave of such work in the Report 1883, p. 319, taken from among the subjects of inquiry assigned to Committees of the Association during the past five years, and rearranged as follows, in the order of the Sections that are now severally concerned in them :—(A) Luminous meteors; meteoric dust in various localities; rainfall; underground temperature. (C) Erosion of sea-coasts; height of underground waters; erratic blocks. (D) Migration of birds at lighthouses and lightships; periodical natural phenomena (flowering of plants, &c.); injurious insects (their first appearance, &c.). (F) Working of Education Code in elementary schools; rudimentary science in schools. (G) Effective wind-pressure on buildings. (H) Photographs of typical races and crosses; ancient earthworks; prehistoric remains; anthropometric collections.

They have placed only one Society (the Liverpool Astronomical Society) on the selected list which published no results of local scientific investigation during the past year; they have included it, and some others whose publications of that description were few, on account of their general scientific activity and influence.

Two Societies—the Inverness Scientific Society and the Isle of Man Natural History and Antiquarian Society—have been included in the selected list, and the titles of the papers furnished by their secretaries, as read before them in 1884, have on this occasion been catalogued, although the publications have not yet been received. It is proposed that for the future Rule 5 be strictly adhered to.

The Committee are glad to find that the Societies they have selected prove to be evenly distributed throughout the United Kingdom.

SELECTED LIST

OF SOCIETIES RECOMMENDED BY THE CORRESPONDING SOCIETIES COMMITTEE FOR ELECTION AS

Corresponding Societies of the British Association.

Title of Society	Abbreviated Title	Index No.
Aberdeen Natural History Society . . .	Aberdeen N. H. Soc.	1
Barnsley Naturalists' Society	Barns. Nat. Soc.	2
Bath Natural History and Antiquarian Field Club .	Bath N. H. A. F. C.	3
Belfast Naturalists' Field Club	Belfast Nat. F. C.	4
Birmingham Natural History and Microscopical Society	Birm. N. H. M. Soc.	5
Birmingham Philosophical Society . . .	Birm. Phil. Soc.	6
Burton-on-Trent Natural History and Archæological Society	Burt. N. H. Arch. Soc.	7
Cambridge Philosophical Society	Camb. Phil. Soc.	8
Cardiff Naturalists' Society	Cardiff Nat. Soc.	9
Cornwall, Mining Institute of	Cornw. Min. Inst.	10
Cornwall, Royal Geological Society of . . .	Cornw. R. Geol. Soc.	11
Cumberland and Westmoreland Association for the Advancement of Literature and Science .	Cumb. West. Assoc.	12
Dumfriesshire and Galloway Scientific, Natural History, and Antiquarian Society . . .	Dum. Gal. Sci. N. H. Soc.	13
East of Scotland Union of Naturalists' Societies .	E. Scot. Union	14
Edinburgh Geological Society	Edinb. Geol. Soc.	15
Essex Field Club	Essex F. C.	16
Glasgow, Geological Society of	Glasgow Geol. Soc.	17
Glasgow, Natural History Society of . . .	Glasgow N. H. Soc.	18
Hertfordshire Natural History Society and Field Club	Herts. N. H. Soc.	19
Holmesdale Natural History Club . . .	Holmesdale N. H. C.	20
Inverness Scientific Society and Field Club . .	Inverness Sci. Soc.	21
Liverpool Astronomical Society	Liv'pool Ast. Soc.	22
Liverpool Engineering Society	Liv'pool E. Soc.	23
Liverpool Geological Society	Liv'pool Geol. Soc.	24
Liverpool, Literary and Philosophical Society of .	Liv'pool Lit. Ph. Soc.	25
Manchester Geological Society	Manch. Geol. Soc.	26

SELECTED LIST OF SOCIETIES—*continued.*

Title of Society	Abbreviated Title	Index No.
Man, Isle of, Natural History and Antiquarian Society	I. of Man N. H. A. Soc.	27
Marlborough College Natural History Society .	Marlb. Coll. N. H. Soc.	28
Midland Union of Natural History Societies .	Mid. Union	29
North of England Institute of Mining and Mechanical Engineers	N. Eng. Inst.	30
North Staffordshire Naturalists' Field Club and Archæological Society	N. Staf. N. F. C. A. Soc.	31
Northamptonshire Natural History Society and Field Club	N'ton. N. H. Soc.	32
Perthshire Society of Natural Science . . .	Perths. Soc. N. Sci.	33
Rochester Naturalists' Club	Rochester N. C.	34
Scottish Geographical Society	Scot. Geog. Soc.	35
South African Philosophical Society	S. African Phil. Soc.	36
Warwickshire Naturalists' and Archæologists' Field Club	Warw. N. A. F. C.	37
Yorkshire Geological and Polytechnic Society .	Yorks. Geol. Poly. Soc.	38
Yorkshire Naturalists' Union	Yorks. Nat. Union	39

Index of Papers referring to Local Scientific Investigations published during the Past Year by the above-named Societies.

Section A.—MATHEMATICAL AND PHYSICAL SCIENCE.

Name of Author	Title of Paper	Abbreviated Title of Society	Index No.	Title of Publication	Volume or Part	Page
Berridge, W.	Meteorological Notes	Mid. Union	29	*Mid. Naturalist*	VII.	66, 98, 141, 206, 236, &c.
Evans, F. G.	Meteorological Report	Cardiff Nat. Soc.	9	*Rept. and Trans.*	XVI.	68
Fielding, Rev. C. H.	Summers of 1868 and 1884	Rochester N. C.	34	*Roch. Naturalist*	6	124
Gamble, J. G.	The Barometer and the Winds. Presidential Address	S. African Phil. Soc.	36	*Trans.*	III.	xix.
Harvey, Rev. C. W.	Meteorological Observations taken at Throcking, Herts., during the year 1883	Herts. N. H. Soc.	19	„	III.	103
„ „	Report on the Rainfall in Hertfordshire in 1883	„ „	„	„	„	112
Knowles, J.	On an Electric Current down Rivin Pit, near Bolton	Manch. Geol. Soc.	26	„	XVII.	345
M'Lellan, D.	Meteorological Notes for 1883, and Remarks on the State of Vegetation in the Public Parks of Glasgow	Glasgow N. H. Soc.	18	*Proc. and Trans.*	I.	80
Preston, Rev. T. A.	Weather Report	Marlb. Coll. N. H. Soc.	28	*Report*	33	114
„ „	Results of Twenty Years' Observations on Meteorology taken at Marlborough College, 1865–84	„ „	„	*Special Report.*		
Reeve, A.	Meteorological Summary (1884)	Burt. N. H. Arch. Soc.	7	*Annual Report*	Ninth	22
Terry, H., and F. Law.	Meteorological Observations	N'ton. N. H. Soc.	32	*Journal*	3	22, 54, 101, 150
Turtle, L.	Meteorological Summary for the year 1884	Belfast Nat. F. C.	4	*Annual Report and Proc.*	II. (Ser. II.)	293
Tyndall, W. H.	Meteorology in 1881	Holmesdale N. H. C.	20	*Proc.*	I.	32
„ „	Meteorological Notes for 1882	„ „	„	„	„	67
White, H.	Remarks on Lightning in the Pit at W. Thornley Colliery, on Dec. 11, 1883	N. Eng. Inst.	30	*Trans.*	XXXIII.	81

Section B.—Chemical Science.

Name of Author	Title of Paper	Abbreviated Title of Society	Index No.	Title of Publication	Volume or Part	Page
Symons, B.	The Maidanpec Wet Process for the Reduction of certain poor Cupreous Ores	Cornw. Min. Inst.	10	*Proc.*	I.	373
Turner, T.	An Analysis of Water from Salt Wells near Dudley	Birm. Phil. Soc.	6	"	IV.	38
Wheaton, Rev. H.	Experimental Agriculture	Rochester N. C.	34	*Roch. Naturalist*	6	103
Whiteley, R. L.	Analysis of the Kissengen (Harrogate) Saline Chalybeate Water, 1883, as compared with Analyses in 1845, 1854, 1867, and 1879	Yorks. Geol. Poly. Soc.	38	*Proc.*	VIII.	366

Section C.—Geology.

Name of Author	Title of Paper	Abbreviated Title of Society	Index No.	Title of Publication	Volume or Part	Page
Aitken, T.	Origin of local Conglomerates	Inverness Sci. Soc.	21	*Trans.*	I.	336
Andrews, W.	On Recent Observations on the Trias in Central Warwickshire	Warw. N. A. F. C.	37	*Proc.*	—	19
" "	The Great Chalky Boulder Clay in Central Warwickshire	" "	"	"		32
Beale, C.	The Basalt of Rowley Regis	Mid. Union	29	*Mid. Naturalist*	VII.	109, 126
Bell, D.	Geological Notes from the Land of Lorne (Abst.)	Glasgow Geol. Soc.	17	*Trans.*	VII.	424
Bonney, Prof. T. G.	On the Microscopic Structure of a Boulder from the Cambridge Greensand found at Ashwell, Herts	Camb. Phil. Soc.	8	*Proc.*	5	65
Brodie, Rev. P. B.	An Account of the different Borings in England in search of the Carboniferous Rocks	Warw. N. A. F. C.	37	"	—	34
Brown, H. T.	The Rhætic Beds (Abst.)	Burt. N. H. Arch. Soc.	7	*Annual Report*	Ninth	9
Brown, M. W.	Earth Shakes and Tremors	N. Eng. Inst.	30	*Trans.*	XXXIII.	179
Cameron, D.	Submergence of Scotland	Edinb. Geol. Soc.	15	"	V.	41
Carter, R.	Mineral Wells at Harrogate	Yorks. Geol. Poly. Soc.	38	*Proc.*	VIII.	313
Crosskey, H. W.	Note on Ice-marked Boulders, illustrating the Grooved Blocks of Rowley Hill	Birm. Phil. Soc.	6	"	IV.	69
Davidson, T.	Note on *Lingula Lesueuri*, Rouault	Mid. Union	29	*Mid. Naturalist*	VII.	73

Davis, J. W.	On a New Species of *Heterolepidotus* from the Lias	Yorks. Geol. Poly. Soc.	38	*Proc.*	VIII.	403
Davis, R. H.	The Mineral Wealth of Harrogate	" "	"	"	"	357
De Rance, C. E.	On the Occurrence of Brine in the Coal Measures	Manch. Geol. Soc.	26	*Trans.*	XVIII.	61
Donald, Miss	Notes on some Carboniferous Gasteropoda from Penton and elsewhere	Cumb. West. Assoc.	12	"	IX.	127
Dudgeon, P.	An Altered Trap occurring near Newton Stewart	Dum. Gal. Sci. N. H. Soc.	13	*Trans. and Proc.*	3	11
Durham, J., and W. N. Walker	Report on Geology	E. Scot. Union	14	*Reports*	First	73
Editors	Account of Pencoed Cave Explorations	Cardiff Nat. Soc.	9	*Rept. and Trans.*	XVI.	66
Elsden, J. V.	On the Microscopic Structure of Boulders found in the North of Hertfordshire	Herts. N. H. Soc.	19	*Trans.*	III., 2	47
Eunson, H. J.	On a Probable Fault in the Lias under Northampton	N'ton N. H. Soc.	32	*Journal*	3	169
Fordham, H. G.	Notes on Boulders and Boulder-Clay in North Hertfordshire	Herts. N. H. Soc.	19	*Trans.*	III., 1	33
Forsyth, D.	Notes on the Silurian Rocks of the Muirkirk District	Glasgow Geol. Soc.	17	"	VII.	74
Fraser, J.	Recent Formations and Glacial Phenomena of Strathnairn	Inverness Sci. Soc.	21	"	I.	211
Frecheville, R. J.	On the Umber Deposits at Ashburton	Cornw. R. Geol. Soc.	11	"	X.	217
Gardner, J. S.	The Age of the Basalts of the North-East Atlantic	Belfast Nat. F. C.	4	*Annual Report and Proc.*	II. (Ser. II.)	254
George, T. J., and B. Thompson	A Catalogue of the Geological Collection in the Northampton Museum:—					
	Part 1. The Silurian	N'ton. N. H. Soc.	32	*Journal*	3	39
	Part 2. The Devonian and Old Red Sandstone	" "	"	"	"	154
Gilbert, H. W.	Remarks on the Marine Life of the Reigate District	Holmesdale N. H. C	20	*Proc.*	I.	101
Glen, D. C., and John Young	Notes on the Spherulite Rock of Corriegills and the Banded Pitchstone of Invercloy	Glasgow Geol. Soc.	17	*Trans.*	VII.	352
Goodchild, J. G.	Contributions towards a List of Minerals occurring in Cumberland and Westmoreland	Cumb. West. Assoc.	12	"	IX.	175
" "	The Penrith Sandstone	" "	"	"	"	31
Harrison, W. J.	The Syenites of South Leicestershire	Mid. Union	29	*Mid. Naturalist*	VII.	7, 41
Hemingway, W.	Fossil Flora of Barnsley (continuation)	Barns. Nat. Soc.	2	*Trans.*	IV.	7

Section C.—GEOLOGY—*continued.*

Name of Author	Title of Paper	Abbreviated Title of Society	Index No.	Title of Publication	Volume or Part	Page
Henderson, J.	Suburban Railway Sections, &c.	Edinb. Geol. Soc.	15	*Trans.*	V.	71
Hicks, T., & W. Cash	Fossil Flora of Halifax, Part 4	Yorks. Geol. Poly. Soc.	38	*Proc.*	VIII.	370
Hill, E.	On a Continuous Succession in part of the Guernsey Gneiss	Camb. Phil. Soc.	8	"	5	154
Holmes, T. V.	Notes on the best locality for Coal beneath the Permian Rocks of N. W. Cumberland	Cumb. West. Assoc.	12	*Trans.*	IX.	109
Home, D. Milne	A Greenstone Boulder in North Palmerston Place, Edinburgh	Edinb. Geol. Soc.	15	"	V.	54
Hood, A. W.	Chalk of the Medway Valley	Rochester N. C.	34	*Roch. Naturalist*	4	57
Horne, J.	The Glaciation of the Shetland Islands	Inverness Sci. Soc.	21	*Trans.*	I.	98
"	Old Red Sandstone of Shetland	" "	"	"	"	236
"	Geology of the Nairn and Findhous	" "	"	"	"	283
"	Glaciation of the Orkney Islands	" "	"	"	"	286
Hunter, J. R. S.	The Silurian Mining Districts of Leadhills and Wanlockhead	Glasgow Geol. Soc.	17	"	VII.	373
Jolly, W.	The Last Glacier in Skye	Inverness Sci. Soc.	21	"	I.	25
Kendall, J. D.	Mineral Veins of the Lake District	Manch. Geol. Soc.	26	"	XVII.	292
Kirsop, J.	Notes on a Fall of Dust on March 1, 1884	Glasgow Geol. Soc.	17	"	VII.	428
Kinnear, W. T., & W. Anderson	Carboniferous Crustacea from Ardross Castle	Edinb. Geol. Soc.	15	"	V.	53
Lebour, Prof. G. A.	On a great Fault at Armstead, in Northumberland	N. Eng. Inst.	30	"	XXXIII.	69
" "	On the Breccia-gashes of the Durham Coast and some recent Earth shakes at Sunderland	" "	"	"	"	165
Leitch, J.	Notes on the Geological Formation and Fossils of the Silloth New Dock	Cumb. West. Assoc.	12	"	IX.	169
Livingston, C.	Parallel Roads of Lochaber	Inverness Sci. Soc.	21	"	I.	101
Macconochie, A.	A Review of the Southern Silurian Question	Glasgow Geol. Soc.	17	"	VII.	370
Markham, C. A.	The Great English Earthquake	N'ton. N. H. Soc.	32	*Journal*	3	107
Martin, F. W.	The Geological Section along the West Suburban Railway from Birmingham to King's Norton	Birm. Phil. Soc.	6	*Proc.*	IV.	257
Melly, E. F.	Notes on the Warwickshire Coal Field	N. Eng. Inst.	30	*Trans.*	XXXIII.	151

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On Electrolysis. By Professor OLIVER J. LODGE, *D.Sc.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

WHEN in response to an urgent request by the President of Section B I agreed to open the present discussion, it was only after a good deal of hesitation that I consented. For though convinced of the immense importance of a more thorough study of the facts and phenomena connected with the passage of electricity through decomposable bodies, and of its vital interest to all scientific chemists, yet it was not a subject that I had made specially my own; having been in fact to a great extent deterred by the immense area it covered, and by the somewhat repulsive character attaching to any borderland branch of science—in this case not wholly physics nor wholly chemistry—a repulsiveness perhaps only subjective, and probably to be attributed to a feeling of incapacity for grasping both aspects of the subject with equal completeness. This difficulty still remains with me, and though I have made a severe attempt to tackle the subject as best I could during the past month, I have been quite unable to cover the immense field, or to read more than the summaries of its literature; and accordingly I shall attempt no historical or chronological survey, but shall endeavour simply to direct attention to certain theoretical points which are undoubtedly of interest and importance, and to suggest the answers which I myself feel inclined to give to debatable questions which bristle round even the most elementary facts; in the hope that, attention being thus directed to them, success in finally solving some of them may be attained by a more competent hand.

Naturally I confine myself to the more physical aspect of the subject, because, my chemical knowledge being of a meagre and antiquated description, it is better worth your while that I should attempt reasonably good physics than that I should perpetrate unreasonably bad chemistry.

Moreover no chemical development will be satisfactory and permanent unless erected on a thorough physical basis; and, if I may venture an opinion on such a subject, I believe that the work of a few chemical philosophers spent in broadening and deepening the foundations of their science would soon confer upon the superstructure a less unsightly and lopsided appearance than, seen from outside, it at present has.

The first question which presents itself is—

I. WHAT IS AN ELECTROLYTE ?

The question may have either of two distinct meanings—

(*a*) Is a substance an electrolyte at all; *i.e.*, when alone ?
(*b*) Is it the electrolyte in any particular case; *i.e.*, when mixed with other substances ?

First meaning of I.

As answers to (*a*) certain chemical statements have been made, such as: 'all electrolytes are compounds of a metal with a non-metal' (Miller);

'electrolytes are either simple binary compounds, or are capable of being formed from them by double decomposition, the ions being the radicles so exchanged' (Wiedemann); &c. Such statements may be true, and if true may be important chemical generalisations, but they are not physical definitions or tests of electrolytic conductivity.

As a physical definition of an electrolyte we have only to say, *an electrolyte is a substance which conducts electrolytically.*

A statement like this only helps by fixing our attention on the real point in question, viz. the difference between electrolytic and metallic conduction—a true physical distinction, which is capable of definite examination, and may be capable of precise statement.

Whether we are able thus sharply to divide off electrolytes from other conductors will depend on whether any substance be found which can conduct both like a metal and like an electrolyte. Such a substance is not yet, I believe, certainly known, though it has been often suspected; it has even been suspected that all electrolytes have a trace of metallic conductivity. Though for the present this is quite unproved, and may be regarded as against the weight of evidence, it would be rash to insert the word *wholly* into the above definition; it must be left as meaning that *in so far* as a body conducts electrolytically, so far it is an electrolyte.

Now electrolytic conduction differs from metallic conduction in several ways. Metallic conduction appears to be a true passage of electricity through matter; it is unaccompanied by any reversible or chemical process, it simply generates heat.

Electrolytic conduction is accompanied by certain reversible chemical processes, and appears to be of the nature of a convection of electricity by the atoms of matter.

A substance which so conducts is an electrolyte, and whether it be a good or a bad conductor is foreign to the inquiry.

It is important to notice this because it is often sought to deny that (say) water is an electrolyte by showing that it is a bad conductor. Of course if it *does not conduct at all* it is no electrolyte, but a dielectric. Our definition says first that an electrolyte must conduct, and it then proceeds to say how it must conduct.

Water, alcohol, turpentine, glass, either conduct a little or they do not. If they do not, they are dielectrics pure and simple; but experiments on leaks have always shown a more rapid leak if water, alcohol, or turpentine be used to replace air; and as to some kinds of glass, it seems to be a mere question of temperature whether they conduct or not. If it be proved that any of these things, even when pure, conduct, be it ever so badly, they are not simple dielectrics, and it remains only to consider whether their conduction is metallic or electrolytic.

But it may happen that some of these bodies, or *perhaps* all liquids, behave as dielectrics to rapidly intermittent or alternating E.M.F.s, but as electrolytes to slow and long-continued E.M.F.; just as pitch is elastic to rapid vibrations (it can transmit sound for instance), but is viscous and essentially fluid to long-continued forces. Whether this is so or not is a vital question in relation to the electromagnetic theory of light, wherein the transparency of conducting liquids has only been provisionally and tentatively explained.

Tests for electrolytic conduction as distinct from metallic.

So far as experiment has yet gone, electrolytic conduction is found to obey Ohm's law—a remarkable and important fact, if fact it accurately be—and we will return to it later.

The obedience to Ohm's law shown by electrolytes prevents our drawing any easy and sharp line of demarcation between the two classes of bodies. To distinguish between them we have to study what happens at a boundary or junction of the two classes of conductors.

At such a place Ohm's law utterly breaks down; a finite E.M.F. is needed to drive any permanent current, however small. And the reason is that the atoms which have conveyed the electricity through the electrolyte can accompany it no longer, and have either to give it up and let it go on without them, or cling to it and stop the current. In either case we have what is called polarisation. If the clinging power of the atoms is greater than the applied E.M.F., the current may wholly cease, and as soon as the E.M.F. is removed, will spring back again, the opposition to it being no longer like friction, but like a strained spring.

If the applied E.M.F. overcome the atomic force, the current flows on, leaving the discarded atoms to do what they like. They may combine with each other and separate from the liquid, in which case we have visible chemical decomposition; or they may combine with each other and dissolve in the liquid; or they may combine with the liquid, forming secondary products; or they may combine with the electrodes.

They usually cling tightly to the electrode, even if unable actually to combine with it, and by thus altering its surface they may give rise to a permanent opposite current. The four possibilities are—

Combination with, or solution in, the liquid.
Combination with, or deposition upon, electrodes.
Combination with something already dissolved in liquid.
Combination with each other and freedom.

Wherever visible decomposition occurs, there is no doubt of electrolysis, so that is the most simple and obvious test of electrolytic conduction. But the conductivity may be so bad that no visible product forms in a century. In that case *polarisation*, if present, is a test. As Helmholtz says: 'Galvanometers are sensitive enough to shew a current which could only decompose a milligramme of water in a century.' [1]

But this test also may fail by reason of secondary actions. It is the merest commonplace that an ordinary voltameter behaves as a very leaky condenser. A continual drain of electricity goes through it, however small the E.M.F. applied; and when charged, and left, the charge is found very rapidly to diminish. It is facts like these of course which have so often suggested slight metallic conductivity, and which at one time tempted Faraday to postulate this.

With certain fused salts the decay of polarisation is so rapid that polarisation hardly appears to exist; and quite a strong current can be sent through them without any visible decomposition. Clark [2] has shown that in these cases it is the solution of the liberated ions and their rapid diffusion which causes this apparent metallic conduction. There is pro-

[1] One may notice that even such a current as this is still 10 electrostatic units per second.

[2] J. W. Clark, *Phil. Mag.*, October 1885.

bably a full quota of decomposition, but, unless special precautions are taken, recomposition is just as rapid.

The same thing goes on far more slowly in dilute acid, especially if it contain dissolved gases; and the experiments of Helmholtz with an ingeniously contrived gas-free cell, as related in his Faraday Lecture of 1881, may be taken as settling the quantitative question whether this decay of polarisation is any of it due to slight metallic conduction, or whether the whole of it is rigorously due to solution and diffusion of the semi-liberated ions. It is of course true that these experiments do not settle it for *all* electrolytes, but for dilute sulphuric acid at any rate they prove that the diffusion and indirect recombination of the ions accurately account for everything; and that, when these are stopped a voltameter behaves as a good and non-leaking condenser up to a certain E.M.F., beyond which it conducts with visible decomposition.

It may be as well, perhaps, to avoid misconception by stating that, by the solution and recombination spoken of above, I do not absurdly suppose that nascent O and nascent H, respectively dissolved in the liquid, travel to meet each other and recombine. Upon such direct action as that the presence or absence of dissolved air could have no influence. What one supposes to go on is this. Semi-liberated hydrogen, finding dissolved oxygen in its neighbourhood, combines with it; the corresponding oxygen simultaneously liberated at the other pole dissolves in the liquid, and, so replenishing it, keeps the action continuous at a slow rate regulated by the rapidity of diffusion.

I see nothing, however, to prevent a *liberated* ion from dissolving in the liquid, or from diffusing across to the other electrode, where it may combine with the nascent ion, and so reduce the apparent out-put of the cell; and this action, having nothing to do with dissolved air, might go on even in Helmholtz's gas-free cell. But it could not begin, I imagine, unless the E.M.F. were sufficient to set both ions free;[1] consequently, by never applying more than a feeble E.M.F., this disturbing action may be obviated.

When dissolved oxygen already exists, neither ion has really to be set free; consequently even a feeble E.M.F. is sufficient to maintain a weak current.

In cases where the polarisation test for electrolysis thus fails, Helmholtz proposes another, viz.: *Electrolytes do not fall into Volta's tension series.* An assemblage of metals at constant temperature can give no permanent current: introduce an electrolyte into the series, and they can.

On this principle Helmholtz considers he has proved that the conduction of glass is not metallic; for he makes a Daniell cell with a complete glass partition in place of a porous cell, and finds that the glass does not stop the current by polarisation, as a metal partition would, but that the cell behaves exactly like any other cell with an enormous internal resistance.

One more test, those of us who believe in the electrical theory of light may suggest, viz. *transparency.* A conductor, if transparent, must be an electrolytic conductor. Thus a fused salt, if it be clear and transparent and yet conduct well (as argentic iodide does for instance), may be assumed to be an electrolyte, despite the absence of products of decom-

[1] The E.M.F. required to set an ion free enough to enter into solution is almost enough to set it free altogether. The only difference, I suppose, is *pdv*; and at ordinary pressures this is negligible.

position and of polarisation; unless, of course, rigorous proof can be given that its conduction is metallic, which has in no case happened yet.

Electrolytes seem necessarily fluid, and it is difficult to imagine the locomotion of atoms which accompanies electrolysis to go on in a solid body. Mr. Shelford Bidwell, Dr. Silvanus Thompson and others consider they have found solid electrolytes, but it behoves us to be very careful in accepting such an idea; extreme viscosity there may be, as in hot glass, but not the true rigidity of a solid, unless certain proof is forthcoming.

The tests of electrolytic conduction are these four—

1. Visible decomposition.
2. Polarisation.
3. Non-agreement with Volta's series law.
4. Transparency.

We may thus pretty safely distinguish electrolytes from metals, but to certainly distinguish electrolytes from dielectrics is not always easy. True a dielectric does not conduct, but it may break down. How to distinguish an electrolyte from a *weak* dielectric, as, for instance, rare air: this is not easy. An initial E.M.F. is needed to commence disruptive discharge, but that may be easily confused with electrolytic polarisation of electrodes: indeed some facts suggest that there is a considerable surface or boundary resistance which opposes the passage of electricity from metal into rare air and may altogether stop it when very small terminals are used.

Second meaning of I.

Now pass to the second aspect of the question, what is an electrolyte, viz. (*b*) Is a particular substance *the* electrolyte when mixed with other matter?

If a voltameter had a glass partition with a hole in it, no supporter of the view that glass was an electrolyte would contend that the glass conducted some of the current. Similarly with a water partition, or with any water existing *in a mass* in any part of the vessel. Non-conductivity or bad conductivity has thus everything to say to this question, What is *the* electrolyte?

But then, in a solution of acid or salt water, it is not merely mixed with the substance, it is combined with it; and it is very possible that water in this state may conduct readily enough. Information on this head, sure and definite as it seems to me, is given by the simple fact that pure H_2O and pure liquid HCl both almost insulate when separate, but conduct well enough when mixed.

There are, then, four hypotheses concerning the apportionment of the current among the substances in a salt solution.

(1) That the salt alone conducts.

(2) That the water alone conducts.

(3) That the salt and the water share the conduction between them.

(4) That neither salt nor water exist, but that a hydrate is formed, and that this conducts and is decomposed as a whole.

To decide whether when substances are mixed both conduct the current, Hittorf mixed KCl and KI in various proportions, and concluded that the current always travelled through both salts. Buff has made many similar experiments, and agrees. Gore has deposited brass from a

cyanide solution of copper and zinc. True the combined resistance is not the semi-harmonic mean of the separate resistances, but there is no earthly reason why it should be. It is a mere superstition to expect such a result. Even if the substances were really mixed and not combined, it would not be so; unless there were a boundary surface between the media made wholly of stream-lines, *i.e.* a surface across which no electricity flowed.[1]

Another mode of discriminating between the hypotheses is to use intense currents.[2] For with intense currents you are more likely to get off the real ions: secondary actions are hurried, and cannot go on properly. With intense currents the ions are very apt to come off in a very self-combined and energetic state (as ozone instead of oxygen, &c.), and an extra polarisation force accounts for this extra energy; but they do not so easily combine with other matter in the solution.

Now Magnus showed that from a solution of $CuSO_4$ weak currents deposited copper only, while strong currents liberated hydrogen as well. In fact the observation is now a commonplace. But it is much easier to turn copper out of combination than hydrogen. So if copper were the real primary ion there is no call for hydrogen to appear. It looks therefore as if hydrogen were at least *a* primary ion, and possibly the only one. But then, as pointed out by Smee, local exhaustion of the liquid near the cathode may cause such a deficiency of copper in the liquid touching the plate, that, if the current is too intense for diffusion to keep up the supply, hydrogen must perforce be liberated from the simple acid coating of the cathode. Hence in repeating any experiment of this kind it will be necessary to stir or scour the plate constantly and vigorously; and even then there would be some uncertainty about the matter, supposing hydrogen persistently appeared.

Is there any more direct and simple mode of answering the question as to whether the salt or the water or both conduct the current?

Yes, what seems to me a very simple and satisfactory one; by determining at which pole free acid appears; and, if it appears at both, by determining how much appears at either.

For the sake of clearness it may be well to point this out in detail, though indeed it is so simple as hardly to be necessary.

Consider a solution of copper sulphate in water; decompose it with platinum electrodes, and first make the assumption that the *salt* conducts the whole current, or that the real ions are Cu and SO_4. At the cathode Cu appears and is deposited—nothing else happens. At the anode SO_4 appears, decomposes water, forming sulphuric acid, and setting free oxygen. Thus on this hypothesis all the free acid appears at the *anode*.

Next make the assumption that *water* conducts the whole current, so that hydrogen and oxygen are the true ions. At the anode oxygen appears and is liberated—nothing else happens. At the cathode hydrogen appears, decomposes $CuSO_4$, forming sulphuric acid, and setting free copper. So on this assumption all free acid appears at the *cathode*.

[1] This fact, that no crossflow between 'multiple arc' conductors must occur, if their combined conductivity is to be the sum of their separate conductivities, is sometimes overlooked. The covering on ordinary wires supplies the necessary condition; but if the wires touch the law breaks down. To the parts of one conductor the 'divided circuit law' is by no means necessarily applicable.

[2] Meaning always by 'intensity' of current, *strength of current per unit area*, or what is sometimes inconveniently styled 'density' of current.

Finally, let the water conduct $\frac{1}{x}$th, and the salt $\frac{x-1}{x}$th of the current, then the ratio of the free acid formed at anode to that formed at cathode will be $x-1$.

Now I have made many preliminary experiments; avoiding porous partitions of course, as introducing electric endosmose, capillary forces, and all kinds of unknown disturbances; using only two vessels connected with a syphon U tube, and other such arrangements. I find in all cases acid at *both* poles, though, *with platinum electrodes*, usually most at anode. I do not press these preliminary results; a great deal of easy quantitative work suggests itself in this connection, and it is necessary to specify and to vary the concentration of solution and the strength of current used. The *method* is the important thing, and I should like to have it either approved or condemned.

If one uses copper electrodes, the results are somewhat different. On the hypothesis that the salt alone conducts, no free acid should be formed anywhere; the solution should become impoverished at cathode and concentrated at anode—phenomena which are well known to occur to a greater or less extent. If, on the other hand, the water alone conduct, free acid should appear at cathode but not at anode; the solution near cathode should again become impoverished of copper, though not of SO_4; while upon the anode is liable to form a coat of oxide which there is no sufficient supply of free acid near to dissolve off. And all these phenomena are also found to occur. The deposit of oxide on a copper anode is with intense currents most marked, so much so as almost to stop them. It is most instructive to put some dead-beat instrument like Ayrton and Perry's Ammeter into circuit with a copper voltameter too small for the current, and watch the needle descend from the stops quickly almost to 0.[1] Free acid *does* make its appearance at the cathode —and, with intense currents, plenty of it.

Roughly one may judge perhaps that the salt conducts about three-fourths of the current and the water one-fourth, but I have no certain data yet for any such statement; and the proportion may well vary, for all I know, with the current intensity. One may, however, definitely accept hypothesis 3 or 4 as certainly truer than 1 or 2.

The fact that acid is produced at anode, and alkali at cathode, in the decomposition of, say sodic sulphate, proves that the salt conducts at least some of the current; and an estimation of the amount of acid and alkali respectively generated would decide what proportion was so conducted.

Again, experiments with electrolytes in series, as made by Hisinger, by Berzelius, and by Davy, are interesting in their bearing on this point.[2] Thus, take three vessels containing, say, HCl, HNO_3, and $AgNO_3$; or Na_2SO_4, HCl, and $BaCl_2$, respectively; and the formation of a precipitate is a good identification of a true ion. The *locality* of such precipitate is still more instructive, since it conveys information as to the relative rates at which the opposite ions travel, and so leads us on to the next question, concerning what is called 'the migration of ions.'

[1] Hence, in arranging such voltameters, the anode should be larger than the cathode.

[2] An old experiment of Faraday's (Exp. Res. 494) on the formation of magnesic hydrate at a junction of Epsom salts and water when a current passes, is now accepted, even by Kohlrausch, as proving that water may in some cases conduct.

II. The Migration of Ions.

Do the opposite ions in solutions travel at different rates? And, in any case, at what rate do they travel?

Here, as is well known, we must draw a distinction between fused and dissolved compounds. Fused or homogeneous electrolytes, in which no solution occurs, must always remain of uniform composition; consequently, considering any bounded region, exactly equivalent quantities of either ion must pass out of it on the whole. It is not evident that the two constituents must pass out *in opposite directions*, but in so far as they pass out in the same direction there is no true electrolytic decomposition: there is only a kind of electric endosmose, affecting the level of the fluid as a whole. Given that the level remains uniform, and that ions are only liberated at electrodes, then it is plain that the opposite corresponding ions must pass through any imaginary plane in the fluid at the same rate in opposite directions; for, if not, the constitution of the fluid would not remain uniform.

This argument fails to apply to *dissolved* salts, and it breaks down before long even with fused salts if they dissolve one of the liberated elements or any other body, because *in a solution* no necessity for uniformity of composition exists—one portion may be concentrated, while another is quite weak; and it is well known that such weakening and concentrating actions do occur in electrolysed solutions: *e.g.*, to specify a hackneyed but sufficiently instructive case, in the electrolysis of dilute sulphate of copper with copper electrodes the solution near cathode becomes weaker, while that near anode becomes stronger, than before. If the anode is arranged above the cathode visible blue streaks descend; if the arrangement is inverted the top liquor gets almost clear. If platinum electrodes be used both sides get weaker, but the cathode side weakens two or three times as fast as the anode side. It is customary to explain these well-known and perfectly certain experimental facts by the obvious and plausible hypothesis that the two ions do not travel both at the same rate through the liquid, but that the SO_4 travels quicker than the Cu. Such an explanation accounts for the phenomenon, but it does not follow that it is certainly the true explanation; and for the sake of examining it more particularly I may be allowed to suggest doubts concerning it. If these doubts have no sound physical basis their statement will only result in their removal, and can do no harm.

First let us quickly see how the hypothesis of unequal velocity accounts for the unequal concentration of solution which is called migration. Let SO_4 travel, say, three times as fast as Cu; and consider an imaginary partition about the middle of the cell. Three atoms of SO_4 travel unit distance through it towards the anode for every atom of Cu travelling unit distance in the other direction; but the number of atoms of Cu and of SO_4 liberated against the electrodes in the same time is four of each: hence the anode region of the cell loses only one SO_4, while the cathode region loses three Cu.

The reasoning may be made to look more general.

Consider a compound, AC, arranged in two vessels with a joining tube; let A be anion and C be cation, and let A travel n times as fast as C, so that through the tube we have n equivalents of A passing for every equivalent of C.

By the time one equivalent of each ion has been liberated against the electrode, the ions transmitted by the tube will be x and nx equivalents respectively: hence the anode vessel will have lost altogether $1 - nx$ equivalents of each ion, and the cathode vessel will have lost $1 - x$ equivalents.

But x and nx together convey the whole current, so $x + nx = 1$.

Thus, then, we have as the respective losses of the liberated elements by the two vessels:

$$\text{Loss in anode vessel . . } = 1 - \frac{n}{1+n} = \frac{1}{1+n};$$

$$\text{Loss in cathode vessel . } = 1 - \frac{1}{1+n} = \frac{n}{1+n};$$

Hittorf's well-known expressions.

Or consider it this way:

By the time one equivalent of copper has been deposited, and one of SO_4 has attacked either the anode itself if of copper, or the water in its neighbourhood if of platinum, forming $CuSO_4$ in the one case, H_2SO_4 in the other—no matter which:—by the time all this has happened, $3x$ atoms of SO_4 have passed from neighbourhood of cathode towards anode, and x of copper have gone the other way.

The cathode liquid has thus lost $1 - x$ of copper, and so must have lost $1 - x$ of SO_4 too, no more and no less, or else it would contain isolated radicles.

The anode liquid has gained these $1 - x$ atoms of SO_4; and they may be also reckoned as $3x$, as we just now saw; wherefore $x = \frac{1}{4}$. The cell happens not to lose any SO_4 by deposition, but, instead, it either loses an equivalent of O or gains an equivalent of Cu, according to the nature of the anode.

So the final result in any case is a transfer of $\frac{3}{4}$ equivalent of SO_4 from cathode vessel to anode vessel, combined with a transfer of $\frac{1}{4}$ equivalent of Cu in the opposite direction: a net loss of $\frac{3}{4}$ equivalent of copper sulphate by the cathode solution: and, in the anode liquid, either a net gain of $\frac{3}{4}$ equivalent of $CuSO_4$, if the anode be copper; or a gain of a whole equivalent of H_2SO_4 combined with a loss of $\frac{1}{4}$ equivalent of $CuSO_4$ and of a whole equivalent of oxygen, if the anode be platinum.

All this is in fair agreement with experiment. The only obviously weak place is that relating to the production of free acid. According to the above it ought to appear, if at all, only at anode; now in practice, if the experiment be tried, it will be found to appear at cathode too. Still, the local concentration changes are satisfactorily and very simply explained by this customary migration hypothesis.

But before we decide that the sufficiency of this explanation proves its necessity or actual truth, let us try whether we cannot get the same result on another, and not only plausible but really quite necessary, hypothesis, viz. the hypothesis that the solvent conducts some of the current as well as the salt dissolved; and let us see whether this alone will not account for the whole 'migration' phenomenon, even though opposite corresponding ions be supposed to travel at equal rates.

By drawing a scheme, say, for the electrolysis of $CuSO_4$ solution with platinum electrodes, we can soon see that this hypothesis will do what is wanted; for we find, that if $CuSO_4$ conducts the whole current, the

decomposed equivalent comes half from each half of the cell—the anode half and the cathode half; whereas, by supposing H_2O to conduct the whole current, $CuSO_4$ is decomposed by secondary action only in the neighbourhood of the cathode, and the amount of salt in the anode portion of the solution remains unchanged. The proper apportioning of conduction, therefore, explains migration just as well as the direct Hittorfian hypothesis.

Moreover, we shall find that this mode of regarding the subject is capable of explaining the formation of free acid or other secondary products exactly where experiment shows them to be formed. If it be found to account for their appearance in precisely right amount, it may be held to be proved; let us therefore examine more closely the full effect of supposing the current to be shared between the two ingredients of a doubly compound liquid in any assigned proportion.

Theory of Double Electrolysis: or the decomposition of a mixture of two substances.

We must begin by excluding the possibility of double decomposition or interchange of radicles, because if such occur there are really not two substances mixed, but four. No stress is to be laid on the word 'mixture,' as distinct from combination; and I shall consider a solution of copper sulphate as a mixture of $CuSO_4$ and H_2O, dilute acid as a mixture of acid and water, without troubling about the perfectly certain fact that all these cases (and probably most other cases) of mixture are really cases of—it may be very feeble—chemical combination. But commonly called 'mixed' solutions, such as the heading might at first sight suggest—like, say, $KI+NaCl$, or even $KI+KCl$—are excluded, not only by double decomposition, but by the presence of water, which is distinctly a *third* substance.

Limiting ourselves strictly then to two substances, *e.g.*, a salt and water, there are still several possible cases:

(1) The liberated ions may belong wholly to one of the two compounds.
(2) The liberated ions may belong one to each of the two compounds.
(3) They may each belong to both.

At first sight the first case is a mere simple decomposition, like that of a fused salt, but not necessarily so; it all depends upon whether the substance is *primarily* decomposed or not—*i.e.* on whether it conducts the whole current or not. If the other substance, whose ions are not liberated, either wholly or partially conducts the current, it is a true case of double electrolysis.

To simplify the problem we will use unalterable electrodes—*e.g.* platinum; and we will suppose that the liberated ions do not dissolve, or at any rate *have not* dissolved, in the liquid, else the mixture will not remain merely dual but will become more complex.

We have next to make some hypothesis concerning the relative speeds of opposite corresponding ions—*i.e.*, of the anion and cation of one and the same substance. For the sake of simplicity I will first make the simplest assumption, in favour of which several considerations may be urged, though none of them are conclusive—viz. that opposite corresponding ions travel at equal opposite rates. We shall find this sufficient to

explain every migration phenomenon, and we can see the effect of generalising it afterwards.

Consider, now, the mixture $AC + A'C'$, where A and A' stand for anions, C and C' for cations.

Let the current be conducted by these two compounds in the ratio λ to λ', so that $\lambda + \lambda' = 1$; and, in order to isolate the portion of the liquid near either electrode and study the changes therein occurring, we may picture the whole fluid as contained in two vessels united by a siphon tube; and we shall call the two vessels the anode vessel and the cathode vessel, respectively.

Further, we may if we like think of AC as sulphate of copper, and of $A'C'$ as water; the products of deposition, or liberated ions, will then be C and A' respectively, and the bye-product AC' will be free sulphuric acid. This example therefore belongs to case (2) above, one ion belonging to each compound; and this will serve well enough as an example to work out.

Picturing the convection of electricity by the ions through the tube, we see that A carries a quantity of negative electricity $\frac{1}{2}\lambda$, A' a quantity $\frac{1}{2}\lambda'$; C carries $\frac{1}{2}\lambda$ of positive electricity, and C' a quantity $\frac{1}{2}\lambda'$. So by the time a unit quantity of electricity has been conveyed, and an equivalent of anion and cation deposited on anode and cathode respectively, the following changes have occurred in the ingredients of the fluid in the two vessels. The cathode vessel has gained $\frac{1}{2}\lambda$ equivalent of C from the anode vessel, but it has lost a whole equivalent by deposition, so its net loss of C, which we may write dC, is $1-\frac{1}{2}\lambda$. Of the other cation it has lost none, and has gained $\frac{1}{2}\lambda'$ from the other vessel, so we may write $dC' = -\frac{1}{2}\lambda'$. Of anodes it has lost some of both, but only by travelling to the other vessel, and accordingly $dA = \frac{1}{2}\lambda$, and $dA' = \frac{1}{2}\lambda'$. Similar reasoning easily applies to the anode vessel.

Then passing from the elements only to consider the compounds, we recognise at once that a compound is lost by the loss of *either* of its elements, and that those elements may be either lost absolutely or may be found in new combinations. We thus soon perceive that the loss of the compound AC in the cathode vessel is equal to its loss of C, *i.e.* to its major loss; that is, $d(AC) = dC = 1-\frac{1}{2}\lambda$. The loss of $A'C'$ in this same vessel is equal to whichever is the bigger of the two losses, dA' or dC'; and as dC' is, in the present instance, not a loss, but a gain, there is no doubt but that $d(A'C') = dA' = \frac{1}{2}\lambda'$.

Similarly with the other vessel.

But there remains to be considered what becomes of the unpartnered balance of all the various elements, for unless dC equals dA in both vessels, there will be in one or other an excess of either A or C—in the present case of A; and, again, unless dC' equals dA' there will be an excess again—in this case of C'; hence we have the new compound AC' formed:—in amount, $d(AC') = dA - dC = dC' - dA'$.

The equality of $dA - dC$ and $dC' - dA'$ is necessary, unless it is possible to obtain isolated ions; and it will be found that they come out equal from the preceding values, and that $d(AC') = -\lambda'$ in the cathode vessel, while in the anode vessel $d(AC') = -\lambda$.

Represent all this now in a table :—

Result of Double Electrolysis on the liquid in anode and cathode vessels, by the time one equivalent of an ion belonging to each substance has been deposited.

Substance	Loss in cathode vessel	Loss in anode vessel	Total loss
A	$\frac{1}{2}\lambda$	$-\frac{1}{2}\lambda$	0
A′	$\frac{1}{2}\lambda'$	$1-\frac{1}{2}\lambda'$	1
C	$1-\frac{1}{2}\lambda$	$\frac{1}{2}\lambda$	1
C′	$-\frac{1}{2}\lambda'$	$\frac{1}{2}\lambda'$	0
AC	$1-\frac{1}{2}\lambda$	$\frac{1}{2}\lambda$	1
A′C′	$\frac{1}{2}\lambda'$	$1-\frac{1}{2}\lambda'$	1
AC′	$-\lambda'$	$-\lambda$	-1

The facts of migration are thus perfectly accounted for, and a good deal beside. Thus free acid is shown to appear both at anode and cathode in the electrolysis of sulphate of copper with platinum electrodes: the amount at anode being $\frac{\lambda}{\lambda'}$ of that at cathode. Hence a determination of the relative amount of free acid in anode and cathode vessels at once gives a means of determining $\lambda : \lambda'$, the proportion in which the current is shared by the two substances, if the above hypothesis be true.

It is easy enough to put Hittorf's migration number n into the above table instead of λ: one has only to write $\frac{1}{2}\lambda = \frac{1}{n+1}$; but only three lines of the table have any meaning on the Hittorfian hypothesis—viz. the first, third, and fifth lines—relating to the loss of the compound AC in the respective vessels; the solvent, or other compound, A′C′, is ignored, and the production of free acid near cathode is not supposed to occur. But it *does* occur, as some preliminary experiments I have made prove.

Our hypothesis makes the formation of acid and everything else independent of intensity of current. Experiment may not confirm this; but then we must remember that we have assumed no *mixture of ions* to be liberated, and it is known that with intense currents some hydrogen is given off at cathode as well as copper deposited. If this be taken into account the reasoning must, of course, be generalised.

A more formidable objection, however, may be made to the theory, viz. that it virtually assumes the conduction by the two sets of atoms to be independent; for instance, the λ portion of current starting fairly away from the neighbourhood of electrodes *via* $CuSO_4$ is supposed to go through $CuSO_4$ all the way, and not to come across patches of water or to take either ingredient of the liquid at random.

Consider for a moment what would happen if this did occur. Take a chain, $CuSO_4$, $CuSO_4$, H_2O, H_2O, H_2O, H_2O, $CuSO_4$, $CuSO_4$, H_2O. Imagine the usual Grotthus action to go on through the chain: the result is $2H_2SO_4$ and $1CuO$. This is an unstable condition, or condition of non-minimum energy; so one H_2SO_4 will combine with the CuO; but it need not combine at once, because there is no need for the two compounds to be formed close together. Hence we must expect free acid sometimes to make its appearance *in the middle of the liquid away from either electrode*, and also for CuO to appear (in the form of some basic salt I suppose) too. Choosing proper materials, an action of this kind might be readily looked for, but I have never heard of its being detected,

and it is so unlike what we know of the behaviour of electrolytes in general that until proof to the contrary is forthcoming I feel compelled to believe that a current fairly starting in AC continues in it all the way, that a current starting in A′C′ likewise continues in that, and that secondary actions, or passage of current from AC to A′C′, only occur in the immediate neighbourhood of the electrodes.[1]

It is easy to illustrate the preceding table of the changes in the solutions by a diagram of a special case :—

Scheme of decomposition of sulphate of copper solution with platinum electrodes on the gratuitous assumption that water conducts $\frac{1}{4}$ the whole current.

Cathode			Anode
←$CuSO_4$	$CuSO_4$	. . . . $CuSO_4$	$CuSO_4$
H_2O	H_2O	H_2O	H_2O ↗
←$CuSO_4$	$CuSO_4$	$CuSO_4$	$CuSO^4$
H_2O	H_2O	. . . . H_2O	H_2O ↗
←$CuSO_4$	$CuSO_4$	. . . . $CuSO_4$	$CuSO_4$
H_2O	H_2O	H_2O	H_2O ↗
←$CuSO_4$	$CuSO_4$	. . . . $CuSO_4$	$CuSO_4$
H_2O	H_2O	H_2O	H_2O ↗

The arrangement of the symbols indicates the constitution before passing the current: the dotted lines and arrows indicate the state of affairs after four units of electricity have passed, on the arbitrary assumption (only made for the sake of illustration) that the $CuSO_4$ conducts three times as much current as the water does, *i.e.* that $\lambda = \frac{3}{4}$ and $\lambda' = \frac{1}{4}$. Inserting these values in the previous table, and multiplying by four, to represent that four units of electricity have passed, it becomes :—

Substance	Loss in cathode vessel	Loss in anode vessel	Total loss
SO_4	$1\frac{1}{2}$	$-1\frac{1}{2}$	0
O	$\frac{1}{2}$	$3\frac{1}{2}$	4
Cu	$2\frac{1}{2}$	$1\frac{1}{2}$	4
H_2	$-\frac{1}{2}$	$\frac{1}{2}$	0
$CuSO_4$	$2\frac{1}{2}$	$1\frac{1}{2}$	4
H_2O	$\frac{1}{2}$	$3\frac{1}{2}$	4
H_2SO_4	-1	-3	-4

[1] It is assumed, in the text, that the ingredients of the liquid are thoroughly mixed. If they are purposely arranged in layers, free acid or free base may certainly make its appearance at the bounding surfaces. In fact, Faraday has observed the phenomenon, Exp. R. § 494 ; for he passed a current from strong $MgSO_4$ solution into 'water' (*i.e.*, really weak $MgSO_4$ sol.) and found a deposit of magnesic hydrate at the layer of demarcation. It is interesting to note that in January 1886 Kohlrausch accepts this experiment as proving that water does in some cases share in the conduction, though he still considers its share as negligible in all but exceedingly weak solutions.

And all this is exactly borne out by the above scheme: for one notes that 3 atoms of acid make their appearance in the anode vessel and 1 atom in the cathode vessel; that $\frac{1}{2}$ an atom of O is transferred one way, and $\frac{1}{2}$ an atom of H_2 the other way; that $\frac{3}{2}$ atoms of Cu travel from anode vessel to cathode vessel, but that 4 are deposited, making the net loss in this vessel $4 - 1\frac{1}{2} = 2\frac{1}{2}$; and so on.

Modification of the above table by the introduction of Kohlrausch's hypothesis that each ion has its own rate of travel.

Consider now what will happen if, instead of assuming that opposite corresponding ions must go at the same pace, we assume that each has its own pace; and that the sharing of the current between the ingredients of the fluid depends on these intrinsic ionic velocities and on the proportion of each substance present.

Of the two compounds AC and A′C′, we must affix a mass-velocity to each ion—say, α, γ, α', γ', respectively; so that

$$\alpha + \gamma \text{ is what we formerly called } \lambda,$$

and $\quad \alpha' + \gamma' \quad$ " $\quad$ " $\quad \lambda'$,

but no longer does $\alpha = \frac{1}{2}\lambda$. So the above table becomes:—

Results of Double Electrolysis, &c.

Substance	Loss in cathode vessel	Loss in anode vessel	Total loss
A	α	$-\alpha$	0
A′	α'	$1-\alpha$	1
C	$1-\gamma$	γ	1
C′	$-\gamma$	γ'	0
AC	$1-\gamma$	γ	1
A′C′	α'	$1-\alpha'$	1
AC′	$-(\alpha'+\gamma')$	$-(\alpha+\gamma)$	-1

This gives the relative formation of free acid in the two vessels exactly the same as before—viz. $\dfrac{\alpha+\gamma}{\alpha'+\gamma'} = \dfrac{\lambda}{\lambda'}$.

It is a trifle more general than the former hypothesis, in the non-equality of α and γ, and of α' and γ', and this fact may furnish a method of distinguishing between the two hypotheses.

From the table we see a way to find these values, thus:

$$\gamma = \text{loss of AC in the anode vessel},$$
$$\alpha' = \text{loss of A}'\text{C}' \text{ in the cathode vessel},$$
$$\alpha + \gamma = \text{gain of AC}' \text{ in the anode vessel},$$

and $\quad \alpha + \gamma + \alpha' + \gamma' \equiv 1.$

In Kohlrausch's theory, indeed, ionic velocities are supposed to be pretty well known, and accordingly we may seek to compare the relative quantity of free acid, found in the two vessels, with the ratio $\dfrac{\alpha+\gamma}{\alpha'+\gamma'}$. But then Kohlrausch's velocity-numbers are founded on a strictly Hittorfian view of migration, and do not depend on the assumed conductivity of all the ingredients present in a fluid: they are intended to stand for

the actual speed of moving salt atoms and the water atoms are neglected. Kohlrausch's numbers are in fact totally different things from our α, γ, α', γ', which include along with the idea of velocity the idea of amount of substance available for conducting the current. In terms of a notation to be used later, $\frac{\alpha + \gamma}{\alpha' + \gamma'} = \frac{N_1 u_1}{N_2 u_2}$.

Generalisation of the above, to suit the case when a mixture of ions may be given off at each electrode.

If we now extend our view a little to cover cases (1), (2), and (3) at the same time—that is, to take account of a possible *mixture* of liberated ions, such as one frequently gets with intense currents, and may get at any time, we must write the actual amount of liberated cations c and c', and of anions a and a', where, of course, $c + c' = a + a' = 1$; and the table becomes the following:—

Results of Double Electrolysis, &c.

Substance	Amount of substance lost by cathode vessel	Amount of substance lost by anode vessel	Total loss
A	α	$a - \alpha$	a
A′	α'	$a' - \alpha'$	a'
C	$c - \gamma$	γ	c
C′	$c' - \gamma'$	γ'	c'
AC	$(c - \gamma)$ or (α)	(γ) or $(a - \alpha)$	(c) or (a)
A′C′	(α') or $(c' - \gamma')$	$(a' - \alpha')$ or (γ')	(a') or (c')
AC′	$(\alpha + \gamma) - c$	$a - (\alpha + \gamma)$	$(a - c)$
A′C	or $c - (\alpha + \gamma)$	or $(\alpha + \gamma) - a$	or $(c - a)$

This table looks more complex than the others because it contains alternatives; they are not ambiguities, and it is easy enough to know in any particular case which is the right alternative, but it cannot be expressed by the general symbols, because it is impossible to know whether $c - \gamma$ or α is going to be the bigger. The rule is that the bigger of the two alternatives about the loss of AC and A′C′ is the true one; and the substance formed will be at the same time decided by the values which in the last two alternative lines come out negative.

Or take it conversely. Suppose A′C is the substance formed in both vessels as the bye-product, then the second set of alternatives are the right ones all through; but if AC′ is the substance formed in both vessels, the first set of alternatives are correct; while, if it should happen that AC′ is formed in the anode vessel and A′C in the cathode, then the first set of alternatives are true for the anode vessel and the second set for the cathode vessel.

With actual chemical substances it is usually easy to see whether the bye-product will be AC′ or A′C, and thus to fix the alternatives. Thus with a solution of copper sulphate, it is plain that the bye-product will be H_2SO_4 in both vessels, and not CuO.[1]

As an illustration of the possibility just mentioned, about the bye-products being different in the two vessels, consider the electrolysis of a

[1] Remember that the electrodes are supposed to be platinum, so that oxygen is liberated; with a *copper* anode it is easy enough to form CuO, as has already been said.

salt of some metal more electropositive than hydrogen—for instance, Glauber's salts. Neither Na nor SO_4 can be liberated—the liberated ions must be H and O; but the water is not merely primarily decomposed, Na_2SO_4 shares in the conduction of the current, and accordingly secondary actions go on, forming acid at anode and alkali at cathode, as is perfectly well known. The last table gives every detail of the action, and points out that in order to determine experimentally how much of the current is conveyed by the salt and how much by the water we have only to measure either the amount of acid or the amount of alkali produced. For in this case $a' = c' = 1$; $a = c = 0$; the production of acid is $\alpha + \gamma = \lambda$, the proportion of current conveyed by the salt; and the production of alkali is precisely equivalent.

General Theory of Multiple Electrolysis.

It is now only a matter of writing to make a table for the most general case of electrolysis of a single liquid containing any number of substances. It is not much use now excluding double decomposition, and we will begin by letting the liberated ions be the most complicated mixture possible.

Mix together the substances $A_1C_1 + A_2C_2 + \ldots + A_nC_n$; the result of the mixing is that each anion is liable to be combined with all the cations, forming $A_1C_1 + A_1C_2 + \ldots$, and so on for the others; say $A_1\Sigma C + A_2\Sigma C + \ldots$; or altogether $\Sigma A.\Sigma C$.

Let the liberated ions be $a_1, a_2, \ldots a_n$, equivalents of $A_1, A_2, \ldots$ &c. and $c_1, c_2, \ldots c_n$, equivalents of $C_1, C_2, \ldots$, &c. respectively.

Let the mass-velocities of the independent ions be

$$\alpha_1, \alpha_2, \ldots \alpha_n \text{ for the anions,}$$

and

$$\gamma_1, \gamma_2, \ldots \gamma_n \text{ for the cations.}$$

Then the following equations hold among the quantities:—

$$\Sigma a = \Sigma c = 1,$$
$$\Sigma \alpha + \Sigma \gamma = 1;$$

and, if it is worth while attempting to specify how much of the current each substance conveys,

$$\alpha_1 + \gamma_1 = \lambda_1; \quad \alpha_2 + \gamma_2 = \lambda_2; \ldots, \text{\&c.}$$

[Further, if my notion is true that an electric current necessarily consists of equal positive and negative currents, $\Sigma\alpha = \Sigma\gamma$. I even venture to think it *probable* that $\alpha_1 = \gamma_1$, $\alpha_2 = \gamma_2$, &c. See below.]

Now the portion of above table referring to the loss of elements is simple enough:—

Element	Amount lost in cathode vessel	Amount lost in anode vessel
A_1	α_1	$a_1 - \alpha_1$
A_2	α_2	$a_2 - \alpha_2$
$\vdots$	$\vdots$	$\vdots$
C_1	$c_1 - \gamma_1$	γ_1
C_2	$c_2 - \gamma_2$	γ_2
$\vdots$	$\vdots$	$\vdots$

But when you come to the compounds there is no definiteness; by reason

of the double decomposition which has gone on. Moreover, there are the apparent alternatives, just as in the last table. To get rid of alternatives, decide that the liberated ions are single, one anion A_k, and one cation C_l, where k and l may be equal as a special case. Then the portion of the table referring to loss of compounds is :—

Original substance	Lost in cathode vessel	Lost in anode vessel	Total loss
$A_1(\Sigma C - C_l)$	α_1	$-\alpha_1$	0
$A_2(\Sigma C - C_l)$	α_2	$-\alpha_2$	0
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$A_k(\Sigma C - C_l)$	α_k	$1-\alpha_k$	1
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$A_n(\Sigma C - C_l)$	α_n	$-\alpha_n$	0
$C_l(\Sigma A - A_k)$	$1-\gamma_l$	γ_l	1

If no double decomposition had gone on, the substances would have simply been A_1C_1, A_2C_2, &c. The meaning of $A_1(\Sigma C - C_l)$ is: all the compounds into which A_1 happens to enter, with the express exclusion of A_1C_l, this being considered separately, along with A_2C_l, A_3C_l, . . ., &c., in the last line of the table.

The remainder of the table, dealing with the secondary or bye-products formed, is too indeterminate to be instructive; for even if double decomposition had been excluded originally, it must be supposed to occur now, and the substances formed can only be written :—

Substance formed in cathode vessel	Amount	Substance formed in anode vessel	Amount
$A_1(\Sigma C - C_1 - C_l)$	$\alpha_1 + \gamma_1$	$C_1(\Sigma A - A_1 - A_k)$	$\alpha_1 + \gamma_1$
$A_2(\Sigma C - C_2 - C_l)$	$\alpha_2 + \gamma_2$	$C_2(\Sigma A - A_2 - A_k)$	$\alpha_2 + \gamma_2$
. . . .	. . .	. . . .	. . .
$A_l(\Sigma C - C_l)$	$1-(\alpha_l + \gamma_l)$	$C_k(\Sigma A - A_k$	$1-(\alpha_k + \gamma_k)$
. . . .	. . .	. . . .	. . .
$A_n(\Sigma C - C_n)$	$\alpha_n + \gamma_n$	$C_n(\Sigma A - A_n - A_k)$	$\alpha_n + \gamma^n$

where $A_1(\Sigma C - C_1 - C_3)$ stands for $A_1C_2 + A_1C_4 + A_1C_5 + \ldots$, or any of them—*i.e.* for all the possible new combinations of A_1 with cations; the C_1 being excluded because A_1C_1 is certainly not a new compound; and C_l being excluded because, being the cation deposited on the electrode, there is bound to be a deficiency of it rather than an excess, unless indeed more is brought over by migration than is deposited.

Cases of even this anomaly were discovered by Hittorf among the iodides and chlorides of zinc and cadmium, especially when dissolved in alcohol; more than one equivalent of iodine is carried over towards anode, as much indeed, in one case, as two equivalents. This, however, is regarded as exceptional by everybody, and is usually explained by supposing a sub-salt to travel bodily with the simple ion thus: $3CdI_2 = Cd + (2CdI + 2I_2)$, where the quantity in brackets may be the true anion. The same idea has been extended to other and more ordinary cases.

Objections to the idea of unequal velocities of anions and cations.

The bare notion of unequal molecular velocity has received considerable and important development at the hands of Quincke, Wiedemann, and Kohlrausch; but they all accept the fact, and suggest modes of accounting for it. We will therefore defer consideration of their theories to a later head. What I wish to point out is that migration data afford no *proof* that ions travel at unequal rates, because the facts can be accounted for without any such assumption, as has been shown at length; but if I have to state what objection I feel towards considering the anion and cation velocity unequal, I can only answer in an unsatisfactory manner as follows:—

1st. Electricity is known to obey the laws of an incompressible fluid; and whether for positive electricity or for negative electricity, this is equally true. It may well be that electricity is far from being such a fluid, or pair of fluids, but there must be some analogy or they would not obey so exactly the same equations. If one allows mental images of electric actions, the guise of an incompressible, indestructible, uncreatable fluid, always flowing in closed circuits, naturally suggests itself for either kind of electricity. Equal quantities of opposite kinds in coincidence do indeed neutralise all electrostatic effect, but one does not conceive of their annihilating each other.

2nd. In certain cases an electric current is *known* to consist of equal opposite streams of positive and negative electricity. In a simple binary (fused) electrolyte this is so (see above); and in the convection portion of the circuit of a Holtz machine it is so.

If provisionally these lemmas be granted, the argument is obvious.

Include one or other such arrangement for insuring equal opposite flow in any circuit, along with many kinds of voltameters. Can one think of unequal rates of flow of opposite electricities in one part of a circuit and equal rates of flow in another? Not unless it is possible for equal streams of opposite electricities to meet and annihilate each other. And if we can thus control and make equal the electric streams without affecting phenomena in the slightest, must they not always be equal?

And it is plain that equality of the electric streams renders necessary the equal speed of anion and cation, since by Faraday's laws atomic charge is constant. Not, indeed, that this rigidly requires that *each* anion should travel at the same rate as its corresponding cation, or that $\alpha_1 = \gamma_1$, $\alpha_2 = \gamma_2$, &c. All is satisfied if the anions *as a whole* travel as quick as the cations as a whole—*i.e.* if $\Sigma\alpha = \Sigma\gamma$; but it is difficult to think of the relation as being always satisfied unless each individual α equals each individual γ: the same kind of argument as that which leads one to 'equate coefficients.' But less rigorous! Granted. I do not pretend that any of this is a rigorous argument; it is little better than a statement of prejudice with an attempt at justification.

To see if any definite and unambiguous experimental answer can be obtained to the question, 'At what rate do ions travel?' I propose to try a modification of those old experiments with electrolytes in series, where a precipitate is formed in the middle one of three vessels. For instance, use $BaCl_2$ in the anode vessel, Na_2SO_4 in the cathode vessel, and in the intermediate vessel, which is to be in the form of a long tube, dilute HCl. Then pass a current, and observe whereabouts, how soon, and with what appearances, the precipitate shows itself.

Innumerable similar experiments suggest themselves, but it is needless to specify any more of them at present.

III. Quantitative Laws of Electrolysis.

The main laws known at the present time concerning the passage of electricity through liquids may be denominated, (*a*) Ohm's or Kohlrausch's, (*b*) Faraday's two laws, (*c*) Joule's, or Helmholtz's, or Thomson's law.

(*a*) *Ohm's Law of Electrolytic Conduction.*

The researches of Kohlrausch and Nippoldt, and several others, give us very good grounds for asserting that, in all ordinary cases of electrolytic conduction, Ohm's law is at least approximately obeyed: currents being proportional to E.M.F. actually applied to the liquid. It is exceedingly important to test this law in liquids with the utmost accuracy, as has been done for metals by a British Association Committee (Maxwell and Chrystal), but the research would be a very difficult one. We have seen reason for guessing that with violent currents the law may perhaps begin to fail, even if it be exact for weak currents; but on Maxwell's theory of light it can hardly be quite exact for any current, because the optical transparency of electrolytes shows that they behave as dielectrics to very rapidly alternating E.M.F.s. But the law is very nearly true any way, and this fact of itself is important, as showing that infinitesimal E.M.F.s can produce a current.

Now if there were any chemical cling between the atoms taking part in conduction this could not be—a finite E.M.F. would be needed to tear them asunder; and this is what physicists mean by using the term 'dissociation' in this connection. The atoms are so free of one another that they must be either really or virtually dissociated. Not all the molecules of the compound need be in this condition, of course, only a certain percentage of them, and the conductivity of the liquid must depend upon the value of this percentage. It may be supposed nil in a perfectly pure homogeneous liquid like H_2O; it may be supposed to be caused by the presence of foreign molecules (*e.g.* of salt or acid); and it may be supposed to increase with rise of temperature.

The transparency of an electrolyte may, however, be explained without assuming any violation of Ohm's law, by supposing that the percentage of dissociated atoms is too small to perceptibly affect the properties of the liquid in bulk. On this hypothesis, rise of temperature, or other mode of increasing conductivity, might perhaps cause some increase in opacity; moreover it is to be remembered that the transparency of electrolytes for long waves is possibly very small.

(*b*) *Faraday's Two Laws.*

(1) The voltametric law.
(2) The law of electro-chemical equivalence.

Law 1 asserts that the amount of electro-chemical decomposition is a precise measure of the amount of electricity conveyed; *i.e.* that no electrolyte for which the law is true possesses a trace of metallic conductivity; or, that electrolytic conduction and chemical decomposition are precisely correlative.

The law has been most exactly verified for nitrate of silver solution

by Lord Rayleigh; for this substance, therefore, we know that it is true to a high degree of accuracy. For other substances our knowledge is at present only approximate, the main difficulty in its verification lying in the prevalence of secondary actions and the confusion they cause. So great is the influence of these actions that in some cases an electrolyte has been asserted to conduct only metallically, and not to be decomposed at all. This has been said, for instance, of the fused iodide and chloride of mercury. A strong current may be sent through these fused salts with carbon electrodes and no products of decomposition shall appear, because they dissolve and diffuse through the liquid with such surprising velocity. J. W. Clark [1] has proved this to be the explanation, and has succeeded in getting off a good supply of mercury, and of iodine or chlorine, by separating the electrodes by a sufficiency of intervening porous material, which, whether it retard true diffusion or not, certainly hinders convection.

But of course such an experiment has no exact quantitative signification until every trace of recomposition is avoided, and the theoretical amount of free ions obtained. And this is just the difficulty; for even in simple acid water, if any air be dissolved in the water it is well known that an insufficient supply of hydrogen comes off, while if the water is *not* saturated with oxygen, the supply of oxygen must be deficient by reason of solution.

If oxygen be estimated by *volume* it will be apparently deficient for another reason; but the better way of estimating it is by loss of weight, which gets over the ozone difficulty.

Helmholtz has taught us how to get over the dissolved air difficulty, by making a most ingenious air-free cell, described in the Faraday Lecture, 1881; and he shows that in such a cell polarisation is produced by infinitesimal currents, and no permanent leak goes on through the cell until the applied E.M.F. attains a certain value. This is a perfectly valid proof that no trace of metallic conduction exists in air-free acid-water, and that accordingly for this substance Faraday's law 1 is true.

We have already expressed the law in several forms of words. Helmholtz expresses it as follows: 'Through each section of an electrolytic conductor we have always equivalent electrical and chemical motion.' And if this fact of equivalent electrical and chemical motion be expressed, as Ampère very naturally expressed it, by calling it a convection of electricity by the moving atoms of matter, we may state Faraday's law 1 thus:

Electrolysis is a kind of electrical convection rather than conduction, each atom carrying a charge with it; and the charge conveyed by every atom of a given substance is the same.

Obviously a vitally important statement if the slight amount of hypothesis involved in it is legitimate, as I fully believe it to be; and it is the one virtually adopted by Clerk Maxwell in his treatise.

Law 2 asserts that when a current is sent through a series of different substances, the mass of each substance liberated (or decomposed, or dissolved, or whatever it is that happens to it) is proportional to its ordinary chemical equivalence: or, that the amount of any substance acted upon during the passage of a given quantity of electricity is equal to its molecular weight divided by its atomicity, or, more explicitly, its molecular weight divided by the number of bonds which under the particular

[1] *Phil. Mag.*, November 1885.

circumstances happen to be loosed or joined, per molecule of that substance, be it element or be it compound.

Evidence for the truth of this law has been accumulated by Daniell and Miller, by Wiedemann, Hittorf, Matteucci, Becquerel, Soret, and Buff. They all separate the anode from the cathode vessel by various devices, and it appears as if the more carefully secondary actions are prevented or allowed for, the more nearly is the law true. It may be sufficient to refer to Wiedemann's 'Elektricität' for an account of a mass of research.

Further evidence may be suggested as given by the behaviour of certain electrolytes in series-contact, without electrodes intervening, after the manner of Davy; for, if two meeting ions were not precisely equivalent, the one in excess would have to appear in a solitary state. Such a phenomenon might be well looked for, but it has never yet been certainly observed.

The physical import of law 2 is that it extends the statement of law 1, about each atom in a single substance having the same definite electric charge, to all electrolytes, and enables us to conclude that a definite quantity of electricity belongs to each unit of affinity of every atom of whatever kind; in other words, that every monad atom or radicle (while being liberated on an electrode, at any rate) has associated with it a certain definite quantity of electricity, no matter from what compound it is being liberated, and no matter what the name of the radicle itself may be; that every dyad radicle has twice this quantity associated with it, every triad three times as much, and so on.

It is impossible to overlook the immense interest of such statements as these to any chemist wishing to grasp the real meaning of chemical combination and affinity. But the tremendous import of the law to physicists also may be more vividly indicated by pointing out that the electric charge of a nascent monad atom is a kind of natural unit of electric quantity, *and that fractional portions of such units are*, in electrolysis at least, *unknown*. One may have integral multiples of this natural unit, as in dyads and triads, but one cannot have submultiples, until chemists discover some quantivalence less than that of hydrogen, or rather until they see reason to abandon the idea that quantivalence proceeds by integers (the basis of their 'atomic theory') altogether.

Maxwell no doubt intends to call attention to the superlative interest of the fact that there appears to be a non-divisible electrical unit, when he calls it 'a molecule (his customary cautious name, intended to include atoms also if they exist) of electricity.' And Helmholtz does not shrink from staring the possibility in the face that electricity may turn out to be as 'atomic' as matter.

Atomic Idea of Electricity; Electrostatic Theory of Chemistry.

Let us first consider what is really the evidence for such a view. Electricity is found to associate itself with the atoms of matter in multiples of one fundamental quantity, but never in fractions of it; it does not then follow that fractions of this quantity are impossible, but it may well be that we have never yet dealt with them. The evidence for the atomic nature of electricity is pretty much of the same nature as that for the atomic nature of matter. Gains and losses of electricity are apparently continuous, but so they are of matter; all that is necessary to satisfy

experience is for the atom of electricity to be smaller than any quantity hitherto measured.

Whether the charge of a monad atom be indivisible or not, it is certainly a natural unit of electricity, and it becomes of great interest to calculate its value. This is easily possible to the same degree of approximation, as we know the size of an atom. The electrical charges in the atoms of a gramme of water are known accurately enough, from ordinary electro-chemical-equivalent determinations, viz. $1{\cdot}5 \times 10^{13}$ electrostatic units of each kind; the number of molecules in a gramme of water may be considered as something between 10^{24} and 10^{25}; and accordingly the charge of a monad atom is something like 10^{-11} or 10^{-12} electrostatic units.

Now this is very small, less than the hundred trillionth of a coulomb, and if it were really an ultimate atom of electricity, it is wholly unlikely that the fact would have been noticed. It is possible, however, to think of some phenomena which may afford an indication one way or the other, and I shall venture to suggest one or two later.

The charge of an atom is so small that its potential cannot turn out high, on any customary hypothesis as to actual atomic magnitude, provided ordinary considerations of electrostatics apply to atoms. It is difficult to know whether they apply or not until it can be shown that absolute vacuum has a specific inductive capacity. The transparency of interstellar space, and the velocity of radiation in it, would seem respectively to answer the question in the affirmative, and to suggest unity as its value. At any rate, when one has no other mode of tackling atomic charges it would seem reasonable to try the ordinary electrostatic laws on them, and see how they fit and what happens.

Consider therefore the following problem.

A number of equal spheres, each charged with a definite quantity of electricity, are commingled with the same number of similar spheres each charged with the same quantity of opposite electricity, the potentials of the spheres being so low that mutual discharge does not occur even during a collision, or so-called 'contact,' of the spheres, and some law of force being assumed between the spheres irrespective of their charges.

I do not propose to attack the problem thus vaguely suggested, because many persons can do it far more easily and thoroughly than I; but certain facts are patent. The potential of each sphere must be lower in the 'combined' state than in the isolated, and, unless an atom be assumed to be extravagantly small compared with the spaces between them in the liquid state, the potential of each isolated atom is but a few volts.

Facts are known which suggest sizes for the actual substance of the molecules, but, without pressing them, one may assume that whereas in the liquid state the distance of the atoms apart is about 10^{-8}, the radius of each of them is about 10^{-9} or even 10^{-10} centimetres; then, the charge of a monad atom being as aforesaid 10^{-11} or 10^{-12}, it follows that its potential, when isolated, is about 3 volts.

If such an atom pair off with another of opposite sign, the potential of each will fall as they approach; becoming, when the distance between their nearest points is one tenth of the radius of either, about 1·2 volt,[1]

[1] See table by Sir William Thomson in *Electrostatics and Magnetism*, § 142.

and falling asymptotically to zero as the distance between them still further diminishes.[1]

It is true that this fall of potential has not the result of postponing mutual discharge *ad infinitum*, however near atoms may approach; but I feel constrained to believe that no such discharge ever in practice occurs, from the fact (if it be a fact) that the whole of a liquid can be electrolysed away, and from the assumption that any such discharged molecules would be wholly intractable to electrical influence. To explain non-discharge we can fall back on the rather dark fact of the enormous apparent dielectric strength of vacuum, combined with the very low potentials to which atoms are charged.

I have tried an experiment of electrifying two falling clouds of lycopodium oppositely, and allowing them to mix, or, so to speak, combine. The result has not yet been satisfactory, but lycopodium granules are coarse and weighty bodies, and are unwieldy representatives of atoms. To get anything like such a quantity of each kind of electricity into the grains of a cubic millimetre of lycopodium as exists in the atoms of a cubic millimetre of water, the charge, and therefore the potential, of each granule would have to be enormous, something like a billion volts: for I find the diameter of a lycopodium granule about ·004 centimetre. It is easy to see that a given quantity of both kinds of electricity, shared among a given bulk of equal and definitely arranged spheres, will raise the potential of each by an amount proportional to its superficies.

It may be noted, as interestingly showing the enormous charges which, distributed among the atoms of a substance, produce such an insignificant potential, *i.e.*, as illustrating the prodigious electrical capacity of molecular arrangement, that if the opposite electricities were extracted from a milligramme of water, and given to two spheres one mile apart, those two spheres would attract each other with a force of ten tons![2] (Cf. Helmholtz, Faraday Lecture, 1881.)

A more hopeful substance than lycopodium, for constructing an artificial chemical compound with, is fine smoke, say of magnesia, which hovers in air for a long time.

But, as Clark and I have observed, it is sufficient to electrify such

[1] Or one might work the argument conversely, and perhaps more plausibly, so as to obtain an estimate of atomic, as distinct from molecular, dimensions. Thus:—

The total charge shared among the atoms of a gramme of water is perfectly well known, viz., 1073 electro-magnetic units of each kind. The heat produced during the formation of a gramme of liquid water from its gaseous constituents is, according to J. Thomsen, 4333 thermal units. If two bodies, or sets of bodies, each charged with that quantity of electricity (one set positive, the other set negative), approach each other so as to do this amount of work, their difference of potential must diminish, during the approach, by 1·7 volt.

The fall may be from 1·7 to nearly 0, as the dissociation idea of electrolysis would suggest. Or it may be from 3 to 1·3, as the guess at atomic dimensions in the above text implies. Or atomic charge may be a thing acquired during the act of combination, as the hypothesis of zero charge in a molecular aggregate like HH or OO would imply; in which case the necessary fall of potential must be 3·4 volts.

The first of these alternatives gives for the diameter of an oxygen atom

$$5{\cdot}6 \times 10^{15}\, x^3;$$

$^1/x^3$ being the number of molecules in a gramme of water.

[2] If any cause could make the positive atoms in a drop of water group together and face the negative across a vacuum, a furious Leyden-jar, or 'Globe-Lightning,' would be produced.

smoke with only one kind of electricity in order to cause the particles to combine or coagulate together—doubtless because of minute differences of potential between them: the aggregations soon becoming very large and giving the appearance of snow.

I now fancy that this same phenomenon of aggregation may go on among the atoms of a gas when it is electrified, and may account for the formation of ozone near an electric machine, for the formation of ammonia from nitrogen and hydrogen, and such like.

(c) *Joule's or Helmholtz's or Thomson's law of the dependence of decomposition E.M.F. on chemical combination-energy.*

The deduction of this law from the first law of thermodynamics may be exhibited perhaps most clearly and briefly as follows:

(i.) Definition of E.M.F. as—the work done in a circuit per unit of electricity conveyed, or $E = W/Q$.

(ii.) Definition of Electro-chemical Equivalent as—the mass of substance decomposed per unit of electricity conveyed, or $\epsilon = m/Q$.

(iii.) Definition of Thermal Equivalent as—the heat set free during the formation of one gramme of the substance from the two radicles into which it has just been supposed to be decomposed, provided that none of the energy remains in some form other than that of heat, $\theta = H/m$.

(iv.) Statement of the first law of thermodynamics applied to the electrical decomposition of the said substance in the given way, on the assumption that the whole of the work done by a current is expended in decomposing the substance,

$$W = JH.$$

The simple algebraic consequence of these four equations is

$$E = J\epsilon\theta,$$

which is shorthand for the law, and may be read thus:—the E.M.F. needed to decompose a substance into given constituents is calculable by simple energy considerations from purely thermo-chemical data.

If θ'' stand for the heat production per dyad gramme-equivalent of the substance (*e.g.* per 18 grammes of water, 98 grammes of sulphuric acid, or 136 grammes of chloride of zinc), it is easy to see that

$$E = \frac{\theta''}{46{,}000} \text{ volts};$$

for $J = 42 \times 10^6$, $\epsilon = \dfrac{\mu}{9{,}660k}$, $\theta'' = \dfrac{2\mu\theta}{k}$, where μ is the molecular weight of the substance as compared with an atom of hydrogen, and k is the atomicity or number of bonds loosed in the decomposition supposed.

Values of θ'' are tabulated direct by Julius Thomsen for a great variety of substances, and are quoted in Naumann's 'Chemie,' vol. i. and also partly in Watt's 'Dictionary of Chemistry'; hence the obtaining of the volts needed to decompose a substance, by simply dividing θ'' by 46,000, is extremely convenient.

IV. Discussion of the law (c), and questions concerning Polarisation.

The chemical changes which go on in a circuit wholly electrolytic, or in any homogeneous portion of a circuit, are decomposition and identical recomposition, and consume no energy; accordingly no fresh E.M.F. is needed to send a current through a circuit wholly electrolytic or through a homogeneous electrolyte, *when the force is really applied to it* (*i.e.*, not merely applied to electrodes), and Ohm's law is possibly obeyed by electrolytes exactly as by metals.

But at junctions of metals with electrolytes, or of electrolytes with one another,[1] permanent chemical changes may occur, and at such places a finite E.M.F. must be situated: and the resultant of these may be negative, when it is called polarisation, or positive, when the whole arrangement is called a battery.

Total polarisation may be regarded as the sum of two kinds:

(*a*) Temporary polarisation, existing during continuance of current.
(*b*) Residual polarisation, existing afterwards.

Residual polarisation is caused by a more or less permanent alteration of the surface of the electrodes by clinging or combined ions. Under this head comes the whole subject of secondary batteries.

Concerning temporary polarisation less is known.[2] On Helmholtz's theory it is caused by the deposited but unliberated and still charged ions being unwilling to part with their charges. Whenever the ions are able to combine with the electrode or with the liquid, and thus retain their charges, temporary polarisation is very small. It seems undoubtedly due to the same circumstances as cause the extra energy of the nascent condition of a substance; and it varies very much with the particular state of combination, or uncombination, into which the ions enter when set free from their former union.[3]

The above expression, in the form $\Sigma\,(J\epsilon\theta)$ or $\frac{\Sigma\theta''}{46{,}000}$, or $\frac{\Sigma\theta^{(n)}}{23{,}000n}$, may be used to calculate the theoretical E.M.F. of a battery cell formed of specified constituents in which known reactions go on.

Now is the law really true? Is E. really the E.M.F. needed to decompose a given substance? Or is it only a partial statement of a truth?

It may at once be admitted that whatever *direct* thermal effects the

[1] Du Bois Raymond proved polarisation to be possible at liquid-liquid junctions. He also asserts the existence of '*innere Polarisation*' in a uniform liquid, which would be contradictory of what is said above; but what he observed is plainly connected with capillary E.M.F. and endosmose, and in the light of these is natural enough.

[2] The experiments of Bernstein, as well as some by Beetz and Edlund, have shown how quickly it can rise and decay with make and break of current; so it is scarcely a valid proof of its complete non-existence when a galvanometer switched into a circuit is not deflected. At the same time no sharp distinction can be drawn between temporary and permanent polarisation, any more than between temporary and permanent magnetism.

[3] Mr. J. Larmor gave a short communication to the meeting, 'On the molecular theory of galvanic polarisation,' which he has expanded to a most interesting paper, and published in the *Phil. Mag.* for November 1885. He shows that polarisation, whether natural or artificial, must necessarily diminish surface tension, without any question of exact reversibility; and he calculates the distance apart of the constituent molecules in the electrical layers of a voltameter-condenser, whose capacity is becoming incipiently non-constant.

current may produce, being an expenditure of energy in other than chemical directions, must lie outside the range of the above law, inasmuch as they falsify the assumption of (iv,). Irreversible or frictional heat, and likewise reversible or thermoelectric heat, must thus be considered separately. If ever the E.M.F. of a cell or a voltameter is seriously different from the value calculated on chemical ground it is to be examined whether there be not local heatings or coolings in the cell, whereby the total E.M.F. may be either diminished or increased, being really the sum of two E.M.F.s., a chemical one and a physical or thermoelectric one.

But all this being understood and allowed for, as was really done by Thomson in his original paper in 1851, is the law sustained by experiment for cases other than the Daniell cell and a few other simple ones?

For instance, when two substances combine and produce heat, is any of the heat a direct result of their union, or are electric currents the direct primary result and heat a secondary or derived result? If any of the heat be primarily generated then it is to be surmised that this portion of the whole combination energy is electrically inactive, having no effect on either the positive E.M.F. of a battery or the negative E.M.F. of a voltameter. Secondary actions for instance: it has long been a subject of debate whether the solution of zinc oxide in acid, or of zinc sulphate in water, contributed its full quota to the energy of the current and the E.M.F. of a cell, or whether the combination of zinc with oxygen was more intrinsically effective.

Joule showed how to attack the question for substances composing batteries, by immersing the battery in one calorimeter and its outer circuit in another. Whatever heat necessarily and intrinsically appears in the cell itself must be heat primarily and directly generated; but if all the heat of the battery can be made to appear in the outer circuit, by making the resistance of this circuit high enough, it is proof positive that the primary result of the chemical changes is electric current, not heat; and so in Joule's experiments with certain substances it appeared to be. More cells have since been tried, with the result that some directly heat, while others directly cool, themselves; though the bulk of their energy still seems to take primarily an electro-kinetic form.

Helmholtz has discussed the whole question from the point of view of reversibility, *i.e.* has applied the second law of thermodynamics as well as the first. Directly this mode of treatment is suggested it is almost obvious that a cell which heats or cools itself must have an E.M.F. variable with temperature, according to the law

$$\mathrm{Q}d\mathrm{E} = -\mathrm{J}\frac{d\mathrm{T}}{\mathrm{T}}\mathrm{H},$$

where H is the reversible heat generated in the cell during the passage of a quantity Q of electricity, and $\frac{d\mathrm{E}}{dt}$ is the rate of change of E.M.F. per degree at the absolute temperature T.

Hence, to investigate the sum of the reversible heat coefficients for a whole cell, it is only necessary to experiment on the variability of its E.M.F. with temperature, and to write

$$\Sigma\Pi = \frac{\mathrm{H}}{\mathrm{Q}} = -\frac{\mathrm{T}}{\mathrm{J}}\frac{d\mathrm{E}}{dt}.$$

The properly calculated E.M.F. is then not simply $\Sigma(J\epsilon\theta)$ but

$$E = \Sigma J(\epsilon\theta - \Pi).^{1}$$

In a Daniell cell it happens that dE/dt, and therefore also $\Sigma\Pi$, is very nearly 0.

It is true that with voltameters a difficulty is often experienced, in reconciling the theoretical conclusion that a certain minimum E.M.F. is essential to the decomposition of a given substance, with the practical observation that any E.M.F., however small, can cause a constant leak through an electrolyte; but it has been pointed out, at sufficient length already, how all this is capable of easy explanation by means of secondary chemical reactions.

For remember that θ is the thermal value of the reaction which actually goes on. Now if the action is such as permits the ions to dissolve in the liquid, or to recombine indirectly with each other, less energy is expended, and less E.M.F. therefore required, than if they were really set free. We must not take θ as measured for one kind of reaction and try to fit it to a case where an altogether different reaction is going on.

Again it may happen (especially with intense currents such as are most easily applied by the use of small electrodes like the ends of Wollaston wire) that ions are liberated in a condition of abnormal activity, as, for instance, oxygen as ozone, antimony in its explosive condition, &c. This necessarily means greater expenditure of energy, in proportion to the thermal value of such extra activity, and accordingly a greater E.M.F. is needed to effect decomposition under these circumstances; *i.e.*, the polarisation E.M.F. rises in value, having been forced as high as 3·3 volts, in the case of dilute acid with platinum points, by Buff.

If all these circumstances are properly taken into account, I am aware of no experimental reason which need cause us to doubt the general truth of the simple law, $E = J\epsilon\theta - J\Pi$.[1]

V. Mechanism of Electrolytic Conduction.

Electrolytic conduction is, I suppose we may say certainly, a convection of electricity by the atoms of matter; but concerning the mode in which the atoms make their way through the fluid there are several hypotheses:

(1) The molecular chain of Grotthus; modified and accepted by Faraday and many others, modified further by Hittorf to explain migration.

[1] The simplest mode of writing the complete law is

$$E = J\epsilon\theta + T\frac{dE}{dT}.$$

From this it follows that if heat of combination is independent of temperature, $\frac{dE}{dt}$ must be constant too; and generally, that

$$-\frac{d^2E}{dT^2} = \frac{d(J\epsilon\theta)}{TdT}.$$

Another way of writing it is

$$E = -TJ\epsilon\int\frac{\theta dT}{T^2}.$$

Mr. Laurie (Proc. R.S.E., 1884–5) investigates the heat of combination of zinc and iodine by measuring the E and dE/dt of a zinc iodine cell.

(2) The dissociation hypothesis of Clausius and Williamson; virtually accepted by Maxwell, modified by Quincke to explain migration, and shown by Kohlrausch to explain the facts of conductivity.

(3) The electrostatic hypothesis of Helmholtz.

1. The Grotthus chain, with its postulated pairings and unpairings, is too familiar to need the smallest description. The only difference between the hypothesis as originally stated and the form in which I suppose Faraday to have held it, consists in whether the direct action of the electrodes be supposed to extend throughout the liquid, affecting and polarising every molecule in it,[1] or whether the electrodes' direct action be considered as limited to a very minute molecular range, all interchanges beyond this range being conducted on diffusion principles or by inter-actions among the fluid atoms themselves.

The only objection that may plainly be urged against the theory is that it seems to require some small force able to effect the necessary initial decomposition, and it suggests that conductivity and tenacity of composition are related to one another in some opposing manner. Facts, however, fail to bear out any such idea; conductivity and chemical tenacity seem independent of one another; and, as has been just said under head 'polarisation,' no finite force, however small, has ever been found necessary to decompose an electrolyte when really applied to it.

In other words, no polarisation exists inside a homogeneous electrolyte; *there is no chemical cling of the atoms there, but only a frictional rub.*

Such a fact as this, if well established, renders necessary *some form* of dissociation hypothesis. A Grotthus chain of quite equidistant atoms might serve, or a momentary dissociation would be sufficient, but no hypothesis which involves a tearing asunder of molecules in the *interior* of a homogeneous electrolyte can be permitted. *Herein lies the great distinction between electrolytes and dielectrics.*

2. The form of dissociation hypothesis suggested by Clausius and Williamson is well known. It supposes that the vast majority of molecules in an electrolyte are quite insusceptible to the influence of electrodes, but that a few of them (the number being increased by complexity of composition and by rise of temperature) are, by collision or otherwise, dissociated, and exist in the free atomic state, each atom with its appropriate charge. These alone feel the influence of the electrodes. According to some statements of this hypothesis the direct influence of the electrode is supposed to reach every dissociated atom in the fluid; according to another the direct electrode action extends only to those atoms which come within a minute range of its surface, everything else being managed by ordinary diffusion, *i.e.*, by the ordinary chance locomotions common to all atoms in a fluid.

Individual atoms, though permitted to recombine as soon as they like, on this theory, are commonly thought of as existing in the dissociated state for a finite time. If there are chemical or other objections to such a view, it need not be held; all that the facts of electrolysis require is the most momentary dissolution of partnership, a temporary but quite perfect freedom, so that the feeblest possible influence may suffice to induce recombination in a definite direction and with some atom other than its former partner. Provided a sufficient supply of such

[1] Grotthus in 1805 supposed electrodes to attract ions according to an elemental inverse square law.

temporary severances occur throughout the liquid, no individual atom need remain in its uncombined state for a thousandth of a second, so far as the phenomena of electrolysis are concerned. But in proportion as the dissociated atoms are few and far between, the longer must they be supposed to continue in a free condition.

Something must here be said concerning the views of Quincke and of Wiedemann on the mechanism of electrolytic conduction.

Theory of Quincke.

Prof. Quincke, adopting the dissociation view of isolated atoms, supposes the electrical charges of opposite ions to be not only opposite in sign but specifically unequal in quantity. He considers the direct action of the electrodes to reach every atom, and to propel the one set one way and the other set at a different speed the other way according to simple electrostatic laws, and thus explains at one step both decomposition and ‘migration.’ Moreover, since the charges of opposite ions are not equal they do not neutralise each other; the resulting molecules are therefore charged with a balance of one or other electricity, and get propelled either with or against the current—thus accounting for electrical endosmose.

Evidently the hypothesis is very elastic, and, if granted, explains the facts; but I must confess to an invincible repugnance to the idea of numerically unequal charges existing in the dissociated atoms of a molecule, as well as to the corresponding idea of all the molecules of an electrolyte being similarly charged.

The laws of Faraday seem to me to point so distinctly to a definite charge for every ion, depending solely on its valency in the compound from which it has just been liberated, that it would require very strong necessity to render palatable any other view. And I find no necessity at all. The inequality of charge is postulated only in order to account for the facts of migration as provisionally understood by Hittorf, *i.e.* for the assumed inequality in pace of opposite ions. Now without pressing unduly the prejudices I have ventured to suggest against such inequality in pace, I may claim to have proved that the facts of migration do not at any rate *necessitate* such inequality; and the facts of migration are all that the theory is based upon.

And as to endosmose: it seems to me very doubtful whether any tendency to electric endosmose exists except in the immediate neighbourhood of a surface; one can only *observe* it in capillary tubes and porous partitions, and it seems allied to surface phenomena in general. It has indeed been elaborately considered by Helmholtz from this point of view, along with the reciprocal phenomenon of the E.M.F. generated by the flow of liquids along tubes.

Theory of Wiedemann.

Prof. Wiedemann's theory of electrolysis is not unlike Prof. Quincke's, but it is based on contact electricity. He supposes the atoms charged by contact with each other, and the molecule charged by contact with the vessel; and, having thus obtained the needful electrifications, decomposition and endosmose naturally follow; moreover endosmose comes

out properly connected with the existence of liquid and solid contact, or surface-action.

But how does this theory explain migration? For the atoms in a molecule, if they electrify each other by contact, necessarily do so with equal quantities; and this is where the theory differs from Quincke's. Wiedemann explains the unequal rate of travel postulated by Hittorf, not by inequality in the propelling force, but (more satisfactorily as it seems to me) by a difference in the resistance met with. He would say that a hydrogen atom slips through the liquid more easily than an oxygen atom, and so gets along faster; moreover, he has conjectured, and experimentally verified within certain limits, that the ease of travelling of a given ion is inversely as the ordinary viscosity of the liquid; so that conductivity and viscosity are inverse to one another. He has further established the important and convenient fact that migration and endosmose are totally distinct things, having apparently no sort of relation to one another.

Wiedemann's theory thus chimes in beautifully with that of Kohlrausch, who postulates a specific velocity for every ion: a velocity which depends only on the nature of the liquid in which it has to travel, and the $\frac{dV}{dx}$ which drives it.

That part of his theory which asserts a connection between conductivity and limpidity is curiously illustrated by the behaviour of water (or saline or acid solutions) at different temperatures flowing through a capillary tube. It is known that hot water flows some five times as fast as cold water through a given tube. It is also known that hot water conducts much better than cold. Further, it is known that if terminals connected to an electrometer are immersed in the liquid at either end of such a tube, an E.M.F. is discovered between them, depending on the rate of flow.

Now J. W. Clark has discovered that, notwithstanding its vastly greater rate of flow, the E.M.F. of hot water is almost identical with that of cold. His untimely death has prevented his publishing this result, but when he told it and showed it me, some year or so ago, I conjectured that the observed E.M.F. must be a sort of residue of the whole generated E.M.F., being the part unable to leak back through the liquid; and I accordingly hunted up data to see whether the extra leakiness or conductivity of hot water might so nearly neutralise the E.M.F. generated by its more rapid flow as to give the same residue of E.M.F. Whether this be the true account of the matter or no, the fact is so. The empirical formula in Naumann giving the conductivity of the liquor used in Clark's experiment (it was salt and water I think), at different temperatures, contains practically the same co-efficients as that giving the viscosity of the same liquid, measured by its flow through a capillary tube.

The observation thus agrees perfectly with the theory of Wiedemann, connecting electrolytic conductivity with mechanical limpidity.

The decrease in liquid viscosity with increase of temperature is remarkable. On any kinetic theory of viscosity, as due to diffusion one would have expected it necessarily to increase with rising temperature. In a gas it does so, as is well known, but in a liquid it does just the reverse. I am unable to suggest any reason for this.

Circumstances affecting Conductivity.

There are two ways of increasing conductivity; increase of dissociation would seem to be the main cause when a weak solution is made stronger; diminished viscosity is probably the main cause when a cold solution is made hotter.

But whether the remarkable change in viscosity caused by rising temperature is essentially the same thing as what appears in electrolysis to be extra dissociation I am not able to conjecture.

Cases where the conductivity reaches a maximum at a certain stage of concentration, and afterwards diminishes as the strength of solution still further increases, are easily explained on Wiedemann's view of viscosity, combined with that of dissociation; for at first the percentage of dissociation may increase faster than does the viscosity, and so conduction be on the whole easier; while at last viscosity must increase fast enough to neutralise the advantage of whatever extra dissociation there may be. Indeed it is probable that dissociation itself may ultimately diminish, notably so for instance with nearly strong sulphuric acid, for it seems roughly to depend on heterogeneity of constitution.

It may be plausibly argued that the experiments of Kohlrausch and Grotrian support the following view. Dissociation, and therefore also conductivity, falls to a minimum whenever the proportion of ingredients present are such as to make a very simple typical compound, such as (markedly) H_2O, or H_2SO_4, or even H_2SO_4, H_2O; but, with intermediate proportions, a certain number of semi-detached radicles are mixed along with these more stable compounds, and high conductivity is the result.

Theory of Kohlrausch.

The fundamental assumptions underlying the beautiful theory of Kohlrausch are the same as those adopted by Wiedemann. He considers electrolytic conduction performed by dissociated atoms, each of which carries the same numerical charge of electricity, one set positive the other set negative. He follows Quincke in considering their motion due and proportional to the slope of potential $\frac{dV}{dx}$; and he accounts for migration by unequal speed of travel. But—and this is the special Kohlrausch idea—every ion is supposed to have a specific velocity, in a given fluid, when urged by a given slope of potential; a velocity wholly independent of all other circumstances. Moreover, all very dilute solutions are found to behave similarly, so that an ion's rate of travel is nearly independent of the nature of the dissolved substance so long as there is not sufficient of it to interfere with the general aqueous nature of the liquid.

Kohlrausch has further shown how to calculate this specific ionic velocity in absolute measure, from conductivity, concentration, and migration, data. And the following table, taken from Clerk Maxwell's 'Elementary Electricity,' embodies some of his results.

Specific Velocity of different ions in centimetres per second when urged in a very watery solution (i.e. *one whose viscosity differs very little from water, no matter what acid or salt is being electrolysed in it*) *when urged by an E.M.F. of one volt per centimetre: according to Kohlrausch.*

Cations:	H	K	Am	Na	Li	Ba	Sr
	·0029	·00051	·00049	·00032	·00020	·00033	·00030
			Ca	Mg			
			·00025	·00022			
Anions:	I	Br	Cl	F	N_2O_3	Cl_2O_3	$C_2H_3O_2$
	·00058	·00056	·00053	·00031	·00050	·00038	·00023

It is only with much misgiving that I venture to criticise so admirable a theory supported by close agreement with experiment; but it seems less dangerous to hesitate unduly over a true theory, than to accept too hastily a false one.

In the expectation that the objections I urge against the entire and comprehensive truth of this doctrine of specific atomic velocity will be speedily met and shattered I proceed to state them.

In the first place I proceed to draw a radical distinction between the *sum* of the velocities of opposite ions and their individual velocities. Even if we admit provisionally that the sum of anion and cation velocities can be calculated from conductivity data, I demur at the partitioning of this velocity u into two unequal portions and affixing a definite velocity to either ion. The only data existing for such apportionment of u, into nu and $(1-n)u$, are the migration data of Hittorf; and I have shown at some length that all the observed facts may be otherwise explained: I even venture to think, *must* be otherwise (or to some extent otherwise) explained.

But, passing over this point, there are doubts about the sufficiency of our present data for u itself. The Kohlrausch theory considers the dissolved salt as the sole electrolyte; it neglects the conductivity of the water.[1] Let us therefore start *de novo* and independently.

Attempt at calculation of absolute ionic velocity.

Let n equal the number of dissociated molecules *of the substance undergoing decomposition* in a liquid, per unit length. Let q equal the total charge (reckoning + and − together numerically), and m the mass of each molecule; and let u be the relative velocity of opposite ions with respect to each other, under the influence of a propelling force $\frac{dV}{dx}$.

Consider an element $dxdydz$. The number of active molecules in its face is n^2dydz, the number leaving it per second is $n^2dydz \cdot nu = n^3u\,dydz$. The quantity of electricity thus conveyed is qn^3udydz per second, and

[1] In the January (1886) number of *Wiedemann's Annalen*, Professor Kohlrausch gives a long account of his present standpoint. In § 20 he discusses this question of the conductivity of water, and sees reason for modifying his original view, and for admitting that in very dilute solutions water does share in the electrolysis.

He mentions, what I did not know, that part-conduction by water had been suggested by Prof. Clausius as accounting for migration; but Prof. Kohlrausch himself adheres to his old Hittorfian view of it.

the corresponding amount of travelling matter is mn^3udydz per second, so that the electrochemical equivalent of the substance is $\varepsilon = m/q$.

By Ohm's law the strength of current is $k\frac{dV}{dx}dydz$, where k is specific conductivity of the solution; hence, since the current is also the quantity conveyed per second,

$$k\frac{dV}{dx}dydz = qn^3udydz,$$

or

$$u = \frac{k\frac{dV}{dx}}{qn^3} = \frac{\varepsilon k}{mn^3}\cdot\frac{dV}{dx}.$$

But mn^3 is the number of grammes of the electrolysed or dissociated substance in a unit cube, and this we may write $N\mu$, where N stands for the number of monad gramme-equivalents of the really electrolysed substance per c.c., and μ is its molecular weight compared with hydrogen. Moreover $\frac{\varepsilon}{\mu}$ is simply the electrochemical equivalent of hydrogen, *i.e.* a constant, say η; so

$$u = \frac{k}{N}\cdot\eta\frac{dV}{dx}.$$

We see then that for a given slope of potential u varies only with $\frac{k}{N}$, or, as Kohlrausch would put it, with conductivity $\div$ concentration, which latter he has proved within certain limits to be nearly constant for many salt solutions.[1]

But the question now arises, is N really simple concentration? What is the substance really undergoing electrolysis? Kohlrausch considers that in weak saline or acid solutions it is the dissolved salt or acid only, and he appears to consider that every molecule of this is effective; hence he would say N is at once determined by knowing how much stuff has been dissolved per litre. Take an example:

A 5 per cent. solution of ammonic chloride contains about ·001 gramme equivalent of the salt per c.c. (*i.e.* say 53 grammes per litre); and it has a conductivity about 9×10^{-6} that of mercury at 0°, or say 10^{-10} absolute units. The E.C.E. of hydrogen is 10^{-4}; so then we can easily calculate the sum of the ionic velocities for the AmCl molecule in such a solution, *on the hypothesis that it is the sole effective compound present, and that the whole of it is effective*—

$$u = \frac{10^{-10}}{10^{-3}}\cdot 10^{-4}\frac{dV}{dx} = 10^{-11}\frac{dV}{dx}.$$

[1] Kohlrausch's latest statements make k/N (understanding N in his sense *pro tem.*), a linear function of $\sqrt[3]{N}$, *i.e.* of the distance between molecules; but the plotted lines showing this are after all very curved, and all that the facts really amount to is, I think, that

$$k = a + bN + cN^2 + \&c.;$$

where a, being the conductivity of pure water, may be taken as zero. The N here interpreted in Kohlrausch's sense, as representing the amount of dissolved salt, I call henceforth N′.

Let the slope of potential be one volt per centimetre, *i.e.* let $\frac{dV}{dx} = 10^8$, then $u = \cdot 001$; and this agrees exactly with Kohlrausch's value; only he apportions it ·00049 to Am, and ·00053 to Cl, upon Hittorfian grounds, instead of half to each.

Ignoring this last mere migration question, what is there hypothetical about the arithmetical problem? Plainly the nature of the substance conveying the current; *i.e.* the value of N.

If what I have said under head 'migration' has any weight, the current is really conveyed partly by the dissolved substance and partly by the solvent, in the proportion of λ to $1 - \lambda$. Let us reconsider the above investigation from this point of view.

Very little change need be made; we shall have n_1^3 and n_2^3 for the number of dissociated molecules of the two substances per c.c., and u_1 and u_2 for their respective ionic velocities. The ratio in which the two substances conduct the current will be $n_1^3 u_1 : n_2^3 u_2$; and corresponding to n_1^3 and n_2^3, there will be N_1 and N_2 to represent the amount of dissociated substance present, reckoned in gramme-equivalents per cubic centimetre of solution; but q remains of the same value as before, and equal to $\frac{N_1}{\eta n_1^3}$ or $\frac{N_2}{\eta n_2^3}$.

So the equation between two expressions for intensity of current becomes

$$k \frac{dV}{dx} = q\,(n_1^3 u_1 + n_2^3 u_2) = \frac{q}{\lambda}\, n_1^3 u_1 ;$$

or

$$u_1 = \frac{\lambda k}{N_1} \cdot \eta \frac{dV}{dx},$$

and

$$u_2 = \frac{(1 - \lambda) k}{N_2} \cdot \eta \frac{dV}{dx}.$$

The value of λ is determined by migration experiments, in the way already explained, and k of course is known; but, since there exists no known means of ascertaining the value of N_1 and N_2, there remains complete uncertainty as to the absolute values of u_1 and u_2; all that one can determine, from conduction and migration data combined, are the values of $N_1 u_1$ and of $N_2 u_2$.

On Kohlrausch's hypothesis, taking the suffix 1 as applicable to dissolved salt, λ is supposed to be 1, and u_2 accordingly 0; moreover, since *every* molecule of the salt is supposed by him to be dissociated sufficiently to take part in the conduction, N_1 is considered known from concentration data, *i.e.* from the percentage of salt contained in the water, and thus u_1 is calculable.

Permitting ourselves to doubt all this, we come to the conclusion that we do not yet know the absolute velocity of any ion, and cannot know it without further information regarding the dissociation ratio (that is, N_1/N', or N_2/N') of each substance present.

On the unlikely supposition that this criticism be in any sense accepted, what is the meaning of the striking agreement between Kohlrausch's theory and experiment?

His view leads to the equation

$$k\eta \frac{dV}{dx} = N'u,$$

where N' is the total number of monad gramme-equivalents *of the dissolved substance* in a cubic centimetre of solution.

Our view, on the other hand, leads to the equation

$$k\eta \frac{dV}{dx} = N_1 u_1 + N_2 u_2,$$

where $N_1 + N_2$ represents the (unknown) amount of *actually conducting substance* per c.c. of solution.

Now it seems by experiment that k/N' is an approximate constant,[1] at any rate for weak solutions; so we must suppose the fact to mean that $N_1 u_1 + N_2 u_2$ is, within limits, nearly proportional to N'.

It is in no way surprising that the dissociation of both substances should proceed *pari passu* with, and be initially proportional to, the quantity of stuff added to the water; but there remains a further question, which, if I am able to discuss it, shall be considered elsewhere.

Theory of von Helmholtz.

Finally we come to the wide-reaching theory of Helmholtz.

The root idea of this theory is that each kind of matter has a specific attraction for electricity, some kinds for positive, other kinds for negative; that, accordingly, work must be done to separate an atom from its electrical charge, or to remove electricity from an atom of high specific attraction and give it to another lower in the scale. Further, that chemical affinity is mainly due to the electrical attraction of oppositely charged atoms, and that when such atoms combine into a compound molecule they do not discharge into each other, but retain their charge.

Apply this principle to a Daniell cell.

During the action of the cell a certain amount of positive electricity has to leave (deposited) Cu, a substance which attracts it feebly, and enter into union with (dissolved) Zn, a substance which attracts it much; hence is derived the energy or E.M.F. of the cell.

Apply the same principle to a water voltameter. During the passage of a current the charges are torn from hydrogen and oxygen atoms and given to the electrodes, which, if they are platinum, have no special attraction for either electricity; hence arises the E.M.F. of polarisation, or the work needed to decompose the liquid. Work is done, according to this theory, not in tearing the atoms asunder, but in tearing their electric charges from them. If the ions are allowed to enter into combination with some available radicles, in such a way as to retain their charges, polarisation E.M.F. is much reduced. So long as the atoms have not given up their charges they cling to the electrodes and cannot be removed mechanically, say by exhaustion or the like; but if once their charges are given up and molecules of the single substance formed, it makes but little difference to polarisation whether that substance be allowed to dissolve in the liquid or be made to bubble up from it.

But it is to be understood, I believe, that in estimating E.M.F., or effective energy of a cell per unit electricity conveyed, Helmholtz would take into account the energy of all secondary, as well as of all primary actions, 'minor attractions of solvents' as well as affinities of ions.

Helmholtz points out that the interior of an electrolyte can stand not the slightest electrostatic strain, and hence, in so far as a voltameter

[1] See, however, a previous footnote.

behaves as a condenser, it does so by reason of actions going on within the films or boundaries separating the liquid from the electrodes. From observations made with his air-free cell Helmholtz estimates the thickness of these quasi-dielectric films as 10^{-8} centimetre—the customary molecular magnitude.

It seems to me that Helmholtz accepts the possibility that ordinary electrostatic laws may be applied to the interactions of atoms and their charges, and to the attractions of atoms by the electrodes across this thin molecular film. And he points out that the reason so feeble an E.M.F. is sufficient to effect decomposition is just because of the extreme thinness of the film—the slope of potential dV/dx being by no means insignificant.

Helmholtz shows that the analogue between the pre-decomposition state of a voltameter and a condenser of constant capacity is accurately sustained by his air-free cell, charge being proportional to potential down to $\frac{1}{1000}$ volt or perhaps lower; and this fact he considers to prove that by far the greater part of the force binding atoms together, and probably the whole of it, is electrical; for 'if any chemical force bound ions together, requiring work to overcome it, an inferior limit ought to exist to such E.M.F.s as are able to attract ions to the electrodes and charge them as condensers. No indication of any such limit has yet been discovered.'

But while he thus considers it proved that the mightiest chemical forces are really electrical, he by no means denies the existence of others. Atoms cling to electricity, and charged atoms cling to one another, but uncharged atoms may cling somewhat, and this may be the distinction between 'typical compounds' and 'molecular aggregates.' This distinction had been forced upon me also independently, and so I quote it with full agreement. All electrolytes belong to the 'typical compound' class, and it is by means of the charges in these atoms that they are so easily decomposable, notwithstanding their strong affinities. But combination can occur between elements of very weak affinity, which only with difficulty can be got to unite; and yet, once combined, they seem to cling with the most surprising tenacity. These bodies, I should suppose, are molecular aggregates held together by purely 'chemical,' *i.e.* material or non-electrical, forces; and the reason of their apparent tenacity is, I would suggest, merely that they afford no handle to lay hold of. They are quite unsusceptible to electrical influence, unless it be in the violent and perhaps thermal form of the electric spark. If I instance such bodies as cyanogen and ammonia it is only to indicate more suggestively what I mean.

I do not feel sure whether Helmholtz would lend his name to the suggestion just made, for he hedges a little about these molecular modes of combination and says, 'But the fact that even elementary substances with few exceptions have molecules composed of two atoms makes it probable that even in these cases electric neutralisation is produced by combination of two atoms each fully charged, not by neutralisation of every single unit of affinity.' I venture with great deference to suggest, as an objection to this view, the fact that charged (say hydrogen) atoms are unable to unite with each other, though they attack everything else with vigour, but that so soon as they are allowed to give up their charges to an electrode they at once unite and become molecules of gas.

I need not stay to do more than remark that the notion of an attraction between matter and electricity is made by Helmholtz to explain a great many other things—'contact E.M.F.,' 'thermo-electricity,' 'frictional electricity,' and, in fact, all electrostatics and most of current electricity.

These things appear in a great many of his writings, first in his great Memoir of 1847, but they are conveniently summarised in his Faraday Lecture of 1881, from which I have just now been quoting.

It is scarcely decent to obtrude my own opinion on so fundamental a subject as this, but I may be permitted to say that if one does grant such an attraction, and if one further conceives positive and negative electricity as the two constituents of ether, not only chemical affinity but specific inductive capacity and refractive index, together with the Fresnel-Fizeau connection between ether and matter, can be readily conceived and, so to speak, accounted for; and the attraction of gravitation does not lag far in the background. Seven years ago I spent some time endeavouring to set out all these things in a systematic and pretentious form, but I came to the conclusion that the task was beyond my strength. The special things which Helmholtz more particularly explains by his theory—viz. contact E.M.F., thermo-electricity, and frictional electricity—did not suggest themselves to me in such a direct connection with it; nor do they now.

The theory of Helmholtz insensibly impels one to try to apply ordinary electrostatic considerations to the interactions of atoms and to the effect of electrodes upon them. It suggests, in fact, a theory of chemistry; in the form of a sort of supplementary kinetic theory of gases with electrified atoms. But the liquid state, which (more than ever by recent researches[1]) seems essential to chemical action, has difficulties of its own to be overcome before the behaviour of electrified atoms can be properly treated.

It may be noted that whereas the actual force of attraction between two atoms at a distance like 10^{-9} is not great, being something like 10^{-4} dyne, the acceleration produced by it in the small mass of an atom is terrific, being nearly a trillion times that produced in ordinary bodies by the earth. To show that mechanical forces are insignificant compared with electric ones between charged atoms, Helmholtz reminds us that their electric attraction at any distance exceeds their gravitative attraction at the same distance nearly a hexillion times.[2]

[1] Those of Mr. Dixon and others on combustion and on gaseous combination or explosion. As Professor Armstrong has pointed out, they seem to suggest a necessity for the presence of a dissociated typical compound, *i.e.* for electrically charged atoms (see above), in every reaction. Should this turn out to be a fact, it will be one of profound chemical and physical interest.

[2] This is not exactly Helmholtz's way of putting it (Faraday Lecture, 1881), but it comes to the same thing; and it is perhaps as well to notice that there is nothing uncertain about the calculation: the least accurately known datum in it is the gravitation constant, or the earth's mean density. The general expression for the ratio between the electric attraction of two radicles in an electrolytic compound and their gravitative attraction, at any given distance, is

$$\frac{V^2}{4\gamma\mu_1\mu_2\eta^2};$$

where V is the velocity of light, η the electro-chemical equivalent of hydrogen, γ is the gravitation constant, gR^2/E, or $\frac{3g}{8\rho\times10^9}$, while μ_1 and μ_2 are the combining equivalents of the radicles in the compound compared with hydrogen; or $\mu_1+\mu_2$ is the compound's ordinary 'molecular weight' divided by its 'atomicity': *e.g.* for water, $\mu_1\mu_2=8$; for copper sulphate, 80; for silver nitrate, 6696.

The numerical value of the above ratio is

$$\frac{10^{35}}{3\mu_1\mu_2}.$$

VI. Addenda.

Electrostatic calculation of E.M.F. needed to effect decomposition, (a) *of an electrolyte,* (b) *of a dielectric.*

(*a*) I do not think the process is justified by anything Helmholtz has said, but I have allowed myself to reckon through what atomic distances mutual electrical attraction of two charged atoms might be overcome by means of an electrode differing in potential from a liquid by, say, a volt, *i.e.* by means of a slope of potential of 1 volt in 10^{-8} centimetres.

Let y be the effective distance between two oppositely charged atoms in a molecule, so that the force between them is $\frac{q^2}{y^2}$, and let this molecule come within range of the electrode, and so under the influence of the separating stress $q\,\frac{dV}{dx}$; then decomposition will be effected when

$$q\,\frac{dV}{dx} = \frac{q^2}{y^2},\ \textit{i.e.}\ \text{when}\ y^2 = q\,\frac{dx}{dV}.$$

Taking therefore $q = 10^{-11}$, and $\frac{dV}{dx} = \frac{\frac{1}{300}}{10^{-8}} = \frac{1}{3}10^6$, y comes out 10^{-9} or thereabouts—a very respectable atomic distance. This perhaps indicates that, within molecular range of either electrode, actual decomposition or tearing asunder of molecules may occur, but that through the rest of the liquid the action is propagated in some other way, *e.g.* by a divorced atom being projected so close to one of the constituents of a molecule as to combine with it in place of its former partner, and so on.

In this way two postulates may be avoided—1st, the existence of continuous dissociation in ordinary liquids unexposed to electrical influence, a hypothesis to which I understand chemists see some objections; and 2nd, the attraction of matter for electricity postulated by Helmholtz, so far as it is necessary to the explanation of polarisation. Polarisation would then really be the E.M.F. needed to tear asunder molecules of the given compound within molecular range of the electrode; and automatic interactions of the molecules must be trusted to carry the action forward throughout the whole mass.

It appears that on this hypothesis an E.M.F. of one or two volts would be sufficient to decompose acid water, or other similar compound, if atomic distance were something comparable with 10^{-9}. But it may be considered that the magnitude of this distance points to something like at least incipient dissociation as necessary to electrolysis. Let us find its value more carefully.

Put the problem thus:

To find the relation between molecular distance, x, and the least distance at which atomic electric attraction can be overcome by a slope of potential of 1 volt per x centimetres; on the hypothesis that ordinary electrostatic laws are applicable.

$$\frac{V}{x}\,q = \frac{q^2}{y^2}.$$

But $$q = 1{\cdot}5 \times 10^{13} \,.\, x^3,$$

and $$3 \times 10^{10}\,V = 10^8,$$

so $$\frac{q}{V} = 4{\cdot}5 \times 10^{15} \, . \, x^3,$$

and $$y = {\cdot}67 \times 10^8 \, . \, x^2.$$

The most probable value of x at the present time is, I suppose, $\frac{1}{2}\,10^{-8}$; and the fact that y comes out so nearly equal to x is at least noticeable.

Distinction between electrolytes and dielectrics.

Homogeneous electrolytes and dielectrics behave very similarly, when supplied with electrodes at slight difference of potential, but the distinction is that, whereas in an electrolyte the whole of the strain is thrown upon a pair of thin films, the bulk of the medium being as quiescent and unstrained as a metal, in a dielectric the strain exists throughout the medium, sloping steadily down from anode to cathode; if these terms be still permissible. In the one therefore the $\frac{dV}{dx}$ strain is excessive, and very small differences of potential easily cause decomposition; in the other, the strain on each molecule is insignificant—there being a whole series of them to share it—and accordingly it takes a great difference of potential to effect decomposition, or disruptive discharge as it is in this case called, especially if mechanical locomotion of the medium, or a chain of dust particles, be avoided.

In rare gases it seems likely that, by a locomotion of molecules, a steady convective discharge can be maintained, distinct from true disruption; indeed mobility of particles may play an important part in the giving way of any fluid. But, ignoring this, we can reckon roughly on electrostatic principles how much E.M.F. a given thickness of a dielectric ought to bear; and this is what, at the beginning of the present section, I call

(*b*) *Calculation of E.M.F. needed to decompose a dielectric.*

Let the distance of the plates be z; there will be a series of $\frac{z}{x}$ molecules to share the $V-V'$ between them.

Now, since there are about 10^8 molecules per linear centimetre in a liquid, and about 10^9 in an ordinary gas, the slope of potential in a dielectric will be some 10^{-8}th of what it is in the films of an electrolyte for the same potential difference; and accordingly, since it takes one or two volts to decompose a liquid, it will require one or two hundred million volts per centimetre to burst a liquid dielectric, and a tenth of this for a gas. This is probably much too high—certainly it is for a gas; but then what is one to think about the electrification of the atoms of a simple gas like nitrogen? The hint of Helmholtz occurs to one, that possibly even molecules of elements possess some electric charges; and if one could fancy that the atomic charge in such molecules, instead of being 10^{-11}, was something like 10^{-16}, the experimental value of the dielectric strength of air (*viz.* 33,000 volts per centimetre) would be obtained, on the preceding hypothesis; and it would vary with the cube root of the pressure.[1]

[1] On any such theory, the bursting potential will vary as the number of molecules in a row between the plates, *i.e.* as the cube-root of the pressure in the case of a gas. This is by no means true for the potential required to *begin* discharge, but it is not hopelessly out of accord with some measurements by Röntgen (*Wied. Elek.* iv. 465) of the minimum potential sufficient to maintain a discharge already begun

Probably, however, one is now not on the right track, and it is better to refrain from further guess-work; though I must just point out that if one reckons the distance at which fully charged atoms would be able to cling together, on this hypothesis, if they are to give ordinary dielectric strength, though it is too great to be reasonable, it is not outrageously so. The simplest plan is, perhaps, just to quote the arithmetic.

To reckon the greatest atomic distance when the atoms of a molecule are just being torn asunder electrically. Call it y.

The actual stress which can be supported by ordinary air, according to experiment, is given by the equation

$$\frac{V^2}{8\pi z^2} = p = \tfrac{1}{2} \text{ gramme weight per unit are}$$

so a centimetre thickness can stand V = 110 electrostatic units, or 33,000 volts.

This would give a force of 110 dynes per electrostatic unit, or $110 \times 1{\cdot}5 \times 10^{-11} = 1{\cdot}65 \times 10^{-9}$ per atom.

The attracting force of two atoms, at distance y, is $\dfrac{2{\cdot}2 \times 10^{-22}}{y^2}$.

So when a molecule is on the verge of giving way,

$$y^2 = \frac{2{\cdot}2 \times 10^{-22}}{1{\cdot}65 \times 10^{-9}} = 1{\cdot}33 \times 10^{-13},$$

or $y = 3{\cdot}65 \times 10^{-7}$ centimetres, when just giving way.

This is for common air, and is much too big: a stronger dielectric will be satisfied with a smaller limiting atomic range, though still not with one small enough.

It is difficult to suppose that *molecules* tend to get separated instead of *atoms*, and that accordingly ordinary mechanical, not chemical, tenacity is the force to be overcome in a dielectric; for how can this apply to the case of a liquid or a gas?

in pure dry air: as the following table shows. Though indeed the *fourth* root of the pressure would do better still.

Minimum Potential	Pressure	$\frac{V}{\sqrt[3]{P}}$
639	615	75
577	499	73
503	385	69
402	198	69
301	68	74
258	29	84
198	10·9	90
189	7·1	98
	Mean	79

Consequences of an atomic theory of electricity. Possible electrostatic saturation.

The fact that atoms in electrolytes have a constant charge which is the same for every kind of atom, or at least can only be multiplied by an integer, is so striking, that one is constrained to think whether electricity is something necessarily associated with atoms of matter, whether all electrical actions are simple electrostatics among the atomic charges, and whether no quantity of electricity smaller than an atomic charge can exist.

The notion is repugnant, but it just wants considering; though I should hardly have ventured to suggest it but for the support Helmholtz has given to the view as at least a possible one (see above).

The first difficulty which meets us is the serious one that, since air and gases are not electrolytes, nothing is known about the atomic charges of their molecules.

On the atomic theory, however, the unit of electricity is about 10^{-11}, and nothing smaller is possible; so we must provisionally use this as applicable even to air atoms; for it is hardly reasonable to suppose that the aqueous vapour, or other true compound, present is essential to electrostatic actions.

Consider a centimetre cube of air at pressure p dynes per sq. cm.; the number of atoms in it is $\frac{p}{10^6} \cdot \frac{n^3}{800}$ or say $10^{15}\ p$.

The number in each face of the cube is $10^{-6} n^2\ p^{\frac{2}{3}}$, or $10^{10}\ p^{\frac{2}{3}}$.

The available quantity of electricity of either kind on a face of the cube, *when every molecule is fully polarised*, is therefore

$$10^{10}\, p^{\frac{2}{3}} \times 10^{-11} = \frac{p^{\frac{2}{3}}}{10} \text{ electrostatic units.}$$

This is therefore the maximum possible density to which an air condenser could be charged, on the atomic theory.

If p is a millionth of an atmosphere, this gives 400 volts per centimetre as the maximum possible.

If p is 1 atmosphere, it gives 4,000,000 volts per centimetre.

A *liquid* condenser would have 400,000,000 volts per centimetre as its maximum charge.

It is to be understood that this calculation has nothing to do with the dielectric strength of the medium. It is not considered whether the medium can *stand* this stress or not; all that is reckoned is the maximum that can possibly be *produced*, on the atomic hypothesis.

If every dielectric refuses to stand anything like so much, it is difficult to test the hypothesis; but if the maximum possible were to come out something comparable with what a substance under certain conditions can stand, then it may be possible to try the experiment and to discover some evidence of the existence of an upper limit to the charge a condenser, made of that substance, is able to receive.

One effect naturally suggests itself. If the maximum possible charge is insufficient to burst a given kind of condenser then that condenser cannot be burst—it will behave as if infinitely strong.

Now if what I have said has any sense (an improbable assumption) the law of variation of maximum charge with pressure, in a gas, is as $p^{\frac{2}{3}}$.

The dielectric strength of air is ordinarily far below the maximum charge, but if it varies with pressure more rapidly than the $\frac{2}{3}$ power, say as p—it follows that at some high pressure it will overtake the maximum charge and pass above it; and in that case an air condenser at some very high pressure would be unburstable, *i.e.* the dielectric strength of sufficiently high-pressure air would be infinite.

On the other hand if dielectric strength were to vary say as $p^{\frac{1}{2}}$, then very low-pressure air would possess this property.

Experimental evidence tends to show that, over a moderate range, dielectric strength varies roughly as p; but that at very low pressures this law is largely departed from, dielectric strength rapidly falling to a minimum and then apparently increasing again as the exhaustion proceeds.

Cailletet found that air at 50 atmospheres was tremendously strong, a millimetre of it being able to resist a powerful induction coil.

But it is well known that high vacua are apparently very strong too; though the latter is open to a doubt suggested by Schuster, who does not feel sure that the potential applied to small electrodes is really communicated by them to the gas.

Another mode of attacking the question, whether an upper limit to charge exists, would be by seeking for a diminution in the capacity of a condenser when highly charged. It is generally assumed that the capacity of a condenser is a constant quantity; but perhaps our evidence for this is at present insufficient. The electrostatic permeability of a medium (*i.e.* its specific inductive capacity) may be found to diminish with high strain, and tend toward zero, in other words, a dielectric may become 'saturated with electricity,' just as magnetic permeability tends towards zero in a substance very highly magnetised or nearly 'saturated with magnetism.' Unless it has been already done, condensers of various material (and air is the easiest) ought to be examined over a very great range of absolute potential; for a departure from the law of simple proportion between charge and E.M.F. could not fail to have an important signification, whether it be the signification I have hinted at or no.

In conclusion, I must confess that the latter portion of this communication has been perhaps too widely speculative; and it behoves me to explain that only a small portion of the whole paper was spoken by me at the meeting of the Association in Aberdeen; and that in ordering it to be printed *in extenso* the Committee have not made themselves responsible for the contents of the whole. I judged, however, that a little latitude would naturally be allowed in the opening of a discussion, and have therefore set down all the matters which, had time and convenience served, I was prepared to bring forward. The preliminary notes published in 'Nature,' September 10, 1885, will accordingly now serve as a table of contents. I expect my suggestions to receive a severe and salutary criticism, but trust that my admitted ignorance of much that has been done may be pardoned, for it is to be remembered that I was not called upon to draw up a conclusive Report, but to furnish food for reflection and discussion.

List of Suggestions.

It seems permissible and convenient to print here the list of suggestions issued, soon after the meeting, to the Committee appointed jointly by sections A and B, 'for the purpose of considering the subject of Electrolysis in its Physical and Chemical bearings,' in case they might aid any member in deciding on a special subject of investigation.

Some of the statements have been slightly amended; Nos. 11 and 12 have been added.

1. *Is Ohm's law exactly true for Electrolytes?*

We know that it is roughly true for many electrolytes within certain rather wide limits of possible experimental error, but its *exact* verification for any one electrolyte has not yet been attempted, and it is very important. The question is whether, eliminating all effects due to rise of temperature, the resistance-coefficient of an electrolyte is absolutely constant for infinitesimal, ordinary, and powerful currents.

There are two or three plausible ways in which a discrepancy from the exact law may be expected to arise.

(*a*) Supposing the ions absolutely dissociated and to make their way through the liquid according to customary laws of fluid friction, propelled as it were by the electric forces, as is assumed in the theories of Wiedemann, Quincke, Kohlrausch, and others, then so long as the frictional or viscous resistance they meet with varies simply as their velocity, Ohm's law is obeyed. But for very strong currents it is possible that the fluid friction may vary according to a higher power of the speed, and if so, the E.M.F. needed to drive a given current would be a little higher than that calculated from Ohm's law.

(*b*) If the ions are not absolutely dissociated, but exhibit a trace of chemical cling, then some finite though small E.M.F. may be needed to start a current, and thus a violation of Ohm's law may occur in the same direction as that already suggested, but most noticeable with infinitesimal currents. Helmholtz has shown that, for ordinary dilute acid, such an effect, if existent, is almost too small for observation; but in some worse conducting liquids it might conceivably be found.

(*c*) Very viscous or highly resisting electrolytes, such as glass, water, turpentine, &c., may show some discrepancy. In fact, this may be treated as a separate question, and asked thus:

2. *Is Ohm's law obeyed by very bad conductors?*

In other words, is the rate of leakage from a charged electrometer simply proportional to the potential with which it is charged, no matter what kind of slight earth connection is established? Polarisation E.M.F.s are in this case probably too small to have much influence, and so the problem is in some respects simplified. The investigation is in fact precisely similar to an examination of the accuracy of Newton's law of cooling.

Surface films.

Among bad conductors, the films on the surface of glass rods are to be remembered and studied. It would be interesting to know the absolute resistance of some such films, if it be possible to specify their conditions.

Optical observations, combined with electrical conductivity determinations, like those of Reinold and Rücker with soap-films, may be expected to lead to further knowledge of their thickness, nature, &c.

A hygrometer founded on the resistance of such films would perhaps indicate not what is ordinarily called the 'humidity' of the air, *i.e.* its nearness to saturation, but its actual vapour pressure.

Possible methods of answering Question 1.

I find it difficult to make useful suggestions with regard to an experimental attack on the question of Ohm's law in electrolytes.

It is to be remembered that experiment is useless except on a very good and well-considered plan. Something like 1 in 1,000 accuracy must be obtained, and higher may be aimed at.

Although the best experiments hitherto are probably those of Kohlrausch and Nippoldt with alternating currents, it does not seem to me that such currents, employed with electrodes, are suitable for a really accurate determination. The capacity of polarisable electrodes is enormous, and apparently instantaneous, and the use of alternating currents by no means avoids effects due to this polarisation; although it is possible very nearly to eliminate these effects by calculation, as Kohlrausch did.

Methods of avoiding all polarisation, by working in closed circuits wholly electrolytic, are tempting. Such, for instance, as the damping effect, when a magnet swings over a liquid, or when a vessel of liquid is spun between the poles of a magnet (*e.g.* Guthrie and Boys).[1] The electrolyte may be made to partake of the motion of the vessel by using a jelly. But the calculation of such experiments would (to me, at any rate) be difficult, and it is not likely that the experiments themselves are susceptible of minute accuracy.

Probably the best plan of research would be some modification of the ingenious method planned by Maxwell for the British Association Committee on Ohm's law in metals. (See Brit. Assoc. Report, Glasgow.)

If perfectly similar tapping electrodes could be got, it would be sufficient to compare the E.M.F.s at the ends of two troughs or tubes, one wide, the other narrow, placed in series, so that the same current might flow through both. A null method of comparing E.M.F.s is simple enough. For instance, a liquid Wheatstone bridge might be made, one branch consisting of the very wide and very narrow tubes, the other of a uniform tube or trough of moderate width (see figure). A and B are battery electrodes, while C and D, which are carefully chosen, make connection with an electrometer; C being movable. A galvanometer seems dangerous, as allowing slight currents which might disturb the equality of the tapping electrodes.

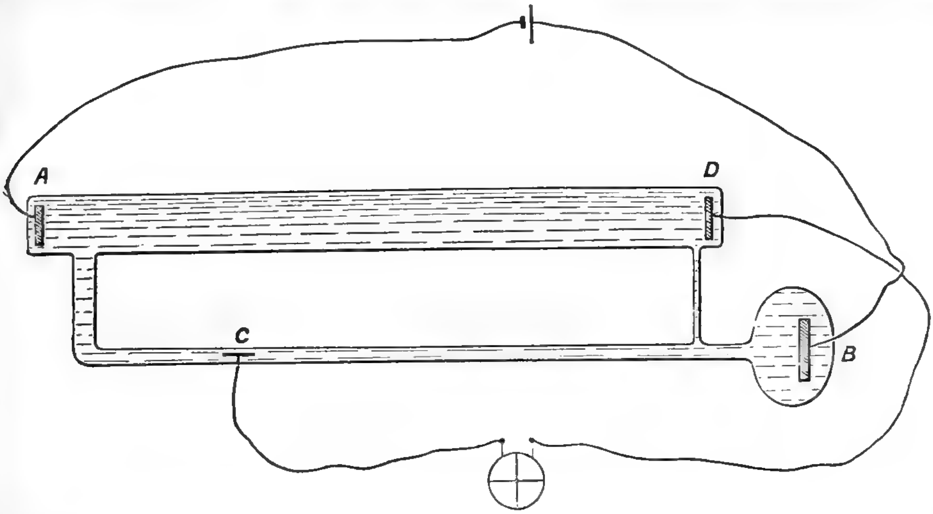
The liquid employed might be chosen for convenience, and a natural liquid to use would be sulphate of zinc, with amalgamated zinc electrodes. It is not to be assumed that the polarisation of these is really nil, but it is certainly feeble, and will thus diminish the uncertainty and risk of error attending the experiment.

To avoid difficulties due to the inevitably unequal rise of temperature, an intermittently strong and weak current can be employed as in the Maxwell-Chrystal method[2] (cf. Schuster, Brit. Assoc. Report, Belfast).

[1] *Proc. Phys. Soc.* or *Phil. Mag.*, 1879 and 1880.

[2] *Brit. Assoc. Report*, 1876, p. 36, Glasgow.

If any positive discrepancy were obtained, it would be necessary to consider to what it was due, and whether the effect of *surface* had anything to do with it. The fine tube might, for instance, be replaced by a



tube packed full of thin glass rod so as to have about the same capacity but much more surface.

3. *Are Electrolytic and Metallic Conduction thoroughly distinct, so that no substance has a trace of both conductivities at once?*

In other words, has any electrolyte a trace of metallic conductivity? or can any compound metal experience a trace of electrolysis? Is electricity able to slip through or among ions, instead of necessarily propelling them; and is it able to do both things at once? A positive answer to this question need not be given in the form of a disobedience to Ohm's law, for there is no reason for supposing that a metallic slip of electricity through the ions would be more prominent with small than with great current intensity.

Insufficient polarisation E.M.F., and constant leakage of a current against it, are the facts which have caused many experimenters to suspect such metallic slip; but secondary actions would so easily account for the same thing, that it is necessary to be extremely cautious in interpreting such observations. Helmholtz's air-free cell proves that if any effect of the kind takes place it must be excessively small for ordinary acid (Faraday lecture). Clark's experiments show that no such explanation of the behaviour of certain anomalous fused salts is *necessary*.[1] But it is impossible to give a certain negative answer to the question, on experimental grounds, until every substance has been tried with minute quantitative accuracy. A positive answer for any substance would of course be a denial of the applicability of Faraday's law to that particular electrolyte.

The second half of the question,

Can any metallic alloy conduct electrolytically?

seems easier of attack.

Experiments have been made, on tin and lead, potassium and sodium,

[1] *Phil. Mag.*, June 1885.

sodium and mercury, gold and mercury, cast-iron, with negative results so far.[1] But none of these alloys except sodium and mercury are well chosen. It would seem advisable to choose two metals far apart in the voltaic series, or in the thermo-electric series, so that one might cling more to positive electricity, and the other more to negative, if possible. Or they might be chosen with their so-called 'specific heats of electricity' very different. Or, again, it may be well to choose two metals differing considerably in conducting power, so that one might be rubbed along with the current, so to speak, more than the other.

I might suggest gold and lead, or copper and tin,[2] or copper and zinc, or bismuth and antimony; beside, of course, mercury and zinc, or mercury and sodium, or, again, copper and zinc dissolved in mercury &c. But it is to be remembered, from the experiments of Dr. Guthrie, Prof. Chandler Roberts, and others, that diffusion in all such cases is excessively rapid, and that precaution must be taken to diminish its effect in restoring uniformity of composition.

A U tube with a constriction at its bend might be used, the whole filled with homogeneous alloy and kept just above the fusing-point. Pass a very strong current through the U, and gradually cool down till the whole is solid, keeping the current on all the time. Then analyse the two legs, and see if they show any difference in composition.

4. *Is there any relation between Optical Opacity and Electrolytic Conductivity?*

Metallic conductors are opaque, but electrolytic conductors are, ordinarily speaking, transparent. At the same time, ordinary water is by no means so transparent as bisulphide of carbon; it absorbs a great deal of some kinds of radiation. Does this opacity increase as conductivity increases, say by addition of acid, and diminish as the water becomes purer; or is there no relation between conductivity and opacity in liquids?

Vision through long tubes is the simplest mode of attacking the question, but to get anything like a complete or satisfactory answer, the absorption spectrum of liquids in the less refrangible ultra-red region would have to be observed.

There are two obvious ways of explaining the transparency of a conducting liquid on the electro-magnetic theory. One is to assume that the minute and rapidly reversed electromotive forces which constitute light are incompetent to effect anything like alternate decomposition and recombination, so that the liquid to such forces behaves exactly like a dielectric; a supposition which would be equivalent to admitting a slight disobedience to Ohm's law, and which is a very reasonable one. The other is to assume that electrolytic conduction only occurs among *dissociated* atoms, and that these free atoms constitute so small a percentage of the total number as not appreciably to affect the transparency or dielectric character of the bulk of the liquid. On this second hypothesis, however, some slight absorption of radiation ought to be expected, and it might increase as the conductivity, *i.e.* percentage of dissociated atoms, increased.

[1] In Mr. Shaw's very useful article 'Electrolysis' in the *Ency. Brit.*, the slip is made of saying that these alloys have been electrolysed.

[2] Prof. Roberts' curious alloy $SnCu_4$ is well worth trying; see *Phil. Mag.*, Dec. 1879, p. 558.

It may be difficult to maintain perfect homogeneity if change of temperature be attempted, else, of course, warming a liquid ought, on this second hypothesis, to make it less transparent.[1]

On the first hypothesis it is possible that exceedingly intense radiation might develop an opacity in liquids quite transparent to ordinary light.

5. *Under what circumstances is solid matter deposited in the Path of a Current?*

It is known, from the experiments of Davy and others, that if at the junction of two liquids the opposite ions can form an insoluble compound, then such insoluble compound is formed, those ions drop out of action, and others have to convey the current. For instance, if a current be sent from a vessel containing a barium salt to another containing a sulphate, through an intermediate vessel containing, say, dilute HCl, then $BaSO_4$ is precipitated in this vessel. I propose to make this intermediate vessel in the form of a tube, and examine whereabouts this formation of $BaSO_4$ first appears; varying intensity of current, density of solutions, &c.; and other similar experiments. (See Question 7.)

Sir Wm. Thomson, at the meeting, made some important observations about deposits of solids in general, and about the possibility of a long-established current producing solid concretions of a nature not naturally to be expected. As, for instance, nodules of copper in the sawdust of a Menotti cell, possible accretions in the joints of animals, &c.

Some porous substance seems most likely, according to present observations, to have such crystals and nodules formed in it; and steady currents might be kept up through porous or cracked crockery, or sawdust, or sand, and secular observations made on the subject.

It is not easy to see why deposits of this latter kind should appear, except by reason of the surface action known as capillary E.M.F. and by some interference with Faraday's law; so that, for instance, the amount of copper going down current, and of SO_4 going up, should not be exactly equivalent, but a slight excess of copper be left, which has to drop out in mid-stream.

If it is allowable thus to regard some deposits as isolated ions, their study becomes of considerable interest.

6. *Is it possible for opposite corresponding Ions to travel at different rates?*

The notion of different speed for different ions is founded upon the facts of 'migration,' but if it can be shown that migration phenomena can be accounted for in another and simple manner, all *necessity* for the hypothesis breaks down.

There only remains the fact that some solutions conduct better than others; and this may be accounted for, either by greater speed of their ions, or by a greater number of dissociated atoms able to take part in the conveyance of electricity. It affords no answer to the question as to whether the opposite radicles travel at the same or at different rates.

In favour of Kohlrausch's and the customary migration theory, it may be truly urged that it is reasonable to suppose that each ion should have

[1] It is here assumed that better conduction means more dissociation; this is not at all certain, it may mean less viscosity; and it apparently does mean this, for the case of rising temperature, though not for the case of increased complexity of constitution.

a rate of travel independent of any other from which it is completely detached; in fact, that it is difficult to see how the velocity of any given radicle can be controlled by the nature of the opposite radicle, which is travelling at its own pace in an opposite direction.

And *against* this independence of the corresponding ions I have only to urge that it would mean that an electric current could consist of *unequal* opposite currents of positive and negative electricity, and that in some cases at least this is certainly not true. Thus, in a simple fused or homogeneous electrolyte, it is quite certain that opposite ions are travelling at the same rate, and that therefore the current in them consists of *equal* opposite streams of positive and negative electricity. Now if such an electrolyte is put in series with salt solutions, and the same current sent through all, it is difficult to suppose that in one part of the circuit the current consists of equal opposite streams, and in another part of unequal; yet this is what Kohlrausch's theory necessitates.

Again, when a Holtz machine or other replenisher is used to produce a current, half the plate is carrying positive in one direction, and the other half is carrying negative in the other direction, so that in the visible convective part of the circuit it is easy to ensure the existence of equal opposite currents; and there is no evidence that the decomposition produced by such currents differs in any respect from that produced by equally strong voltaic currents.

But whence the repugnance to admitting that a current may be at one place $\frac{1}{2}$ positive and $\frac{1}{2}$ negative, and at another place $\frac{3}{4}$ positive and $\frac{1}{4}$ negative? Only from the habit of picturing positive and negative electricity as both obeying the laws of an incompressible fluid, with identity or continuity of existence, and the consequent difficulty of supposing that $\frac{1}{4}$ stream of negative electricity and $\frac{1}{4}$ stream of positive can at one point rush towards each other, meet, and disappear, leaving no trace behind of either. For this is what must happen at the junction of a fused electrolyte, in which opposite ions are going at the same pace, with a dissolved electrolyte, in which the positive ion is travelling three times as fast as the negative ion.

If there is no validity in the objection, then Kohlrausch's theory is probably true pretty much as it stands; but if any difficulty may be legitimately felt in the direction indicated, some modification must be made in Kohlrausch's theory.

7. *On the apparent relative velocity of opposite Ions.*

The facts of migration may, I believe, be accounted for by assuming that the solvent and the dissolved salt *both* conduct the current; but the result is to produce an apparently unequal velocity of ions, which has been mainly examined by subsequent analysis of the liquid near either electrode. I propose to examine it further by means of electrolytes in series:—*e.g.* noting whereabouts in the path of a current a solid precipitate, caused by uniting ions, first forms. I am, indeed, now engaged in these observations (see Question 5).

A disobedience to Faraday's law of electro-chemical equivalence might in the same way be detected, either by an escape of an excess of one ion past another with which it should wholly combine and become insoluble, or by a deposit of the excess of one ion because it finds insufficient of the opposite ion with which to combine and remain soluble.

It may also be possible to examine the speed with which an ion, starting from a vessel at one end of a long tube, makes its appearance in another vessel at the other end of it, there being in this second vessel some sensitive chemical test for faint traces of it; such, for instance, as iron in sulpho- or ferro-cyanide, silver in chloride, copper in ferrocyanide.

Or again, by putting a detecting substance in the tube, the journey of an ion may be continuously watched.

Other things more or less vague might be tried; such as seeing whether there is any difference between applying a high E.M F. to given electrodes in a long narrow vessel, and a small E.M.F. to similar electrodes in a short wide vessel, so that the same current goes through both. One must not expect any variation in the *primary* products of electrolysis probably, but there may be some difference in the secondary effects.

8. *How much of the Current is conveyed by the water and how much by the dissolved salt in any given case?*

To answer this question it seems to me sufficient to determine the amount of free acid generated at either pole, and to compare it with the amount of metal deposited in the same time by the same current.

For instance, with copper sulphate solution and platinum electrodes. If the salt conducted the whole current, one equivalent of free acid would be produced at the anode; if the water conducted the whole, one equivalent of free acid would appear at the cathode; it is easy to see this by drawing the section of a cell and considering its action; and so, by determining the proportion of free acid which actually *does* appear at either pole for given strength of solution and intensity of current, it is easy to reckon how much of the current is by each substance conducted. It is obviously necessary to diminish diffusion between the cathode and anode vessels, and to avoid electric endosmose and the use of porous diaphragms. It is also probably advisable to stir or scrub the surface of both electrodes, so as to avoid a layer of some other liquid forming there, and so confusing the whole reaction.

Migration data, if explained in the way I suggest, will also give a determination of the proportion of current conveyed by salt and by solvent; and it will be interesting to compare the two methods of determination, and see if they give the same result.

If there is a discrepancy, as is very probable, it will be necessary to examine its cause, and to see whether it wholly upsets the suggested migration hypothesis, or only entails some slight modification.

9. *Is any quasi-electrolysis possible across an air-space?*

If there are in acid-water any free dissociated atoms electrically charged, it is just possible, though very unlikely, that they might be pulled out of the liquid by electrostatic attraction.

Thus, if hot acid liquid be one plate of a condenser, the other plate being a hot metal slab half a millimetre above it, and kept at a very different potential, it is just conceivable that the evaporating steam might contain a trace of free hydrogen or free oxygen, according to the sign of the potential of the plate.

10. *Does the energy of Secondary Action contribute to E.M.F. in a cell just as much as the energy of Primary Action, or do secondary actions directly generate heat?*

Dr. Wright distinguishes between what he calls 'adjuvant' and 'non-adjuvant' chemical actions in a cell—those which help the current on, and those which do not.

Lord Rayleigh raised the same question, at the meeting, in considering a Clark cell; for the sulphate of mercury, being nearly insoluble, must certainly be mainly reduced by secondary action if anything like a current is kept going; and yet it seems to contribute to the E.M.F. of the cell.

But one may ask whether the polarisation produced by a moderate current in such a cell is not evidence of the speedy exhaustion of the *dissolved* $HgSO_4$, and of the time taken to replenish the solution from the nearly insoluble paste, thus showing that it is after all the dissolved salt which is really efficient.

Moreover, it seems to me that all reversible effects must contribute to the E.M.F. Helmholtz certainly considers the minor attractions of solvents to be as proportionally effective as the main affinities of ions.

The behaviour of cells which are able to heat or cool themselves, and the variation of their E.M.F. with temperature, are of great interest in the light of the recent theory of Helmholtz. A result deduced from the second law of thermodynamics is pretty surely founded; but experimental verification is always satisfactory, and one can seldom have too much of it.

The laws that want examining are these: Measure the total heat, H, developed per second in cells of various kinds (internal resistance R) by a known current, C; measure also their change of E.M.F. per degree of temperature, dE/dt; then see whether

$$\frac{RC^2 - JH}{C} = (274 + t)\ \frac{dE}{dt}.$$

Further examine whether each of these quantities is also equal to the difference between the observed E.M.F. of the cell and that calculated from purely chemical data, viz. to $E - \Sigma\ (J\epsilon\theta)$.

11. *Is specific inductivity a constant, or does it tend towards zero for very high strains in the same sort of way that magnetic permeability does?*

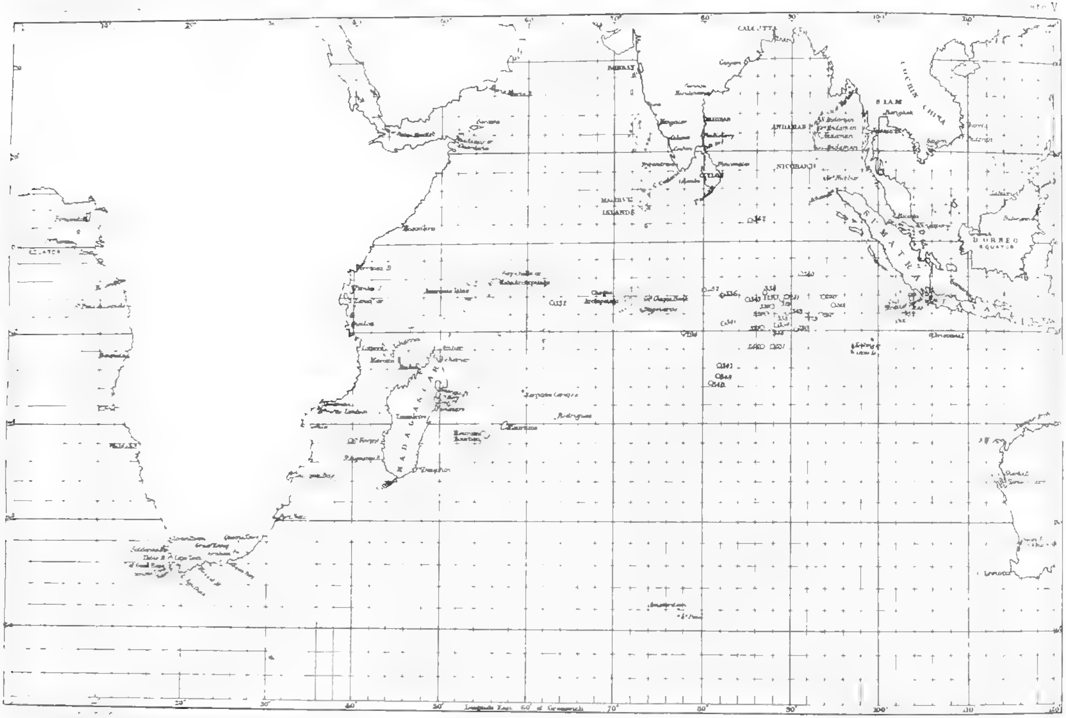
I am not aware that the capacity of a highly-charged condenser has ever been seriously measured. It seems a desirable but difficult thing to do.

12. *How does dielectric strength depend upon density?*

Considerable work has been done in measuring the dielectric strength of different gases at various pressures, but we cannot be said to know the law even for air; nor is the truth about the great strength of approximate vacua on the one hand, and very high pressure gas on the other, at all certain. The dielectric strength of insulating liquids ought also to be measured; and it might be tried how far pressure affects them.

The effect of pressure upon electrolysis has been worked at, and may be said to be fairly understood. The effect of pressure on disruptive discharge, and the internal pseudo-conductivity of gases after elimination of discontinuities such as cathode-resistance, is more obscure.

CHART SHOWING WHEN AND WHERE PUMICE OR VOLCANIC DUST WAS SEEN IN THE INDIAN OCEAN
FROM AUG TO DEC 1883 — THE PLACE OF OBSERVATION IS SHOWN THUS ○, THE DATE IS GIVEN BY THE DAY OF THE YEAR THUS ○300 27TH OCT



Illustrating Mr Meldrum's Tabular Statement of the Dates at which and Localities where Pumice or Volcanic Dust was seen in the Indian Ocean in 1883-84

A Tabular Statement of the Dates at which, and the Localities where, Pumice or Volcanic Dust was seen in the Indian Ocean in 1883–84. *By* CHARLES MELDRUM, *F.R.S.*

[PLATES V. and VA.]

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

Names of Vessels	Month and Day	Hours	Position at Noon		Remarks
			Lat.	Long.	
	1883			E.	
Barque *Actæa* (Capt. Walker)	May 20	2 p.m. to	6° 50′ S.	101° 02′	Very fine dust commenced to fall about 2 p.m. The fall continued all night, and stopped about 9 a.m. on the 21st. Small quantities fell again during the night.
	,, 21	9 a.m.			
	,, 21	night			
Ship *Idomene* (Capt. Johnson)	Aug. 11	8 a.m. to 2 p.m.	6 23 S.	88 31	Passed through large fields of pumice.
Barque *West Australian* (Capt. Thomas)	,, 17	noon	8 35 S.	91 53	Passed a great amount of floating lava or pumice.
	,, 18	noon	9 41 S.	90 28	Passed a great amount of lava to-day.
	,, 19	noon	11 08 S.	88 03	Large quantities of pumice; some pieces about 3 feet in diameter.
S.S. *Anerly* (Capt. Strachan)	,, 27	—	North Watcher		Ashes began to fall at 10.24 a.m. Showers of ashes and pumice lasted till midnight.
	,, 28	—	Auger Roads		Immense quantities of pumice and débris of all sorts.
Barque *County of Flint* (Capt. J. Rowland)	,, 28	noon	8 20 S.	92 04	Great quantity of dust falling; supposed to be coral dust.
French brig *Brani* (Capt. E. Perrot)	,, 28	5 a.m.	4 22 S.	89 14 E. P.	L'atmosphère surchargé de sable. De minuit à 11 heures du matin une très grande quantité de sable très blanc et très fin a couvert toutes les parties accessibles, même presque dans la chambre. Je crois que c'est le résultat d'un orage que nous avions observé ces jours derniers sur Sumatra, pendant lequel le tonnerre avait des roulements

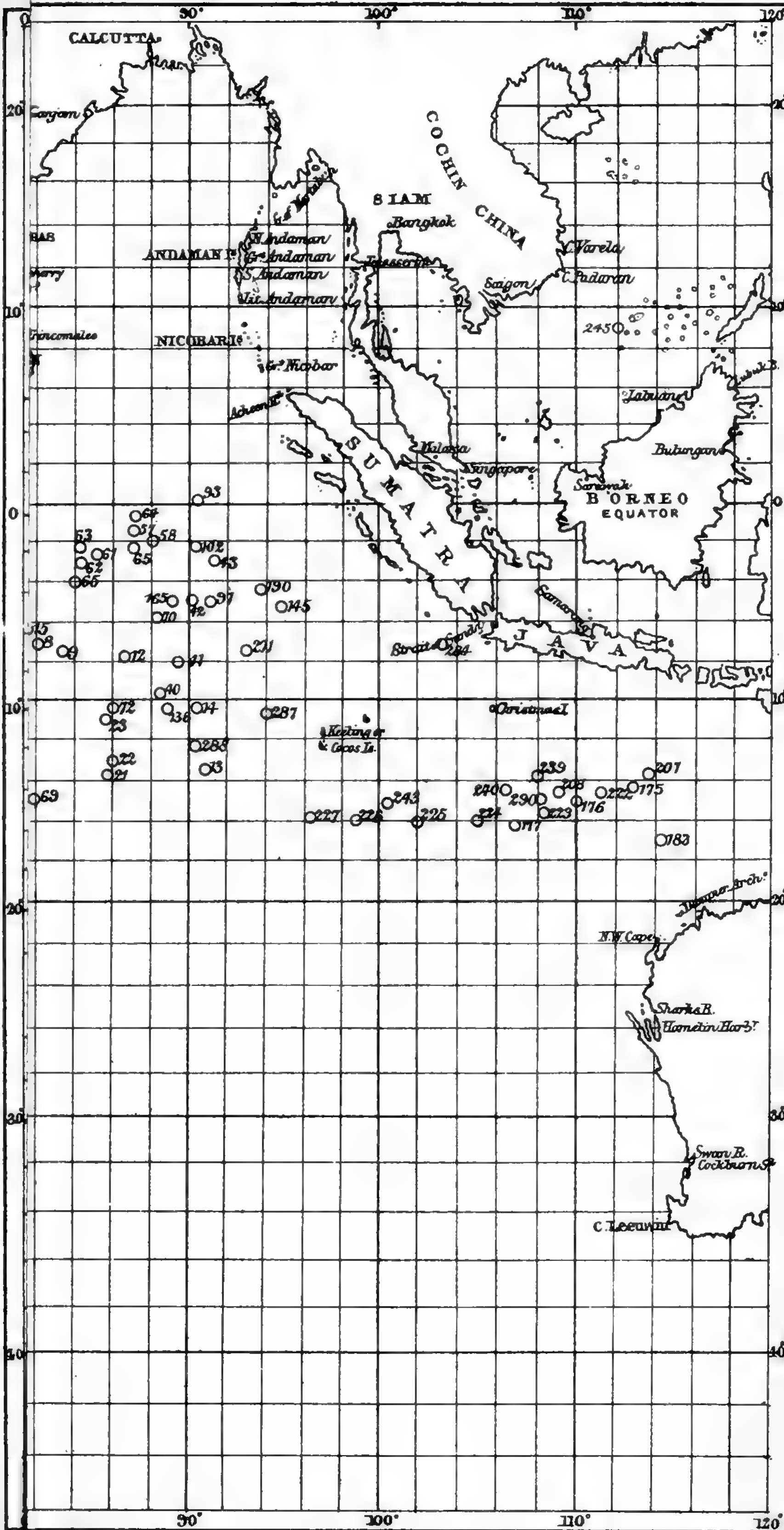
Names of Vessels	Month and Day	Hours	Position at Noon		Remarks
			Lat.	Long.	
	1883		° ′	E. ° ′	
French brig *Brani*—cont.					pareils à une canonnade, et le sable enlevé par cette tourmente a été renvoyé sur nous par la petite brise.
	Aug. 29	9 a.m.	5 50 S.	89 00 E. P.	Il tombe continuellement du sable très fin au point d'obscurcir l'atmosphère.
Barque *Castleton* (Capt. Dioré)	„ 28	2 a.m.	5 58 S.	93 30	After a shower of rain the air became loaded with a fine dust, which fell in great quantities on deck. At noon dust still falling. At 2 p.m. dust still falling.
	„ 29	6 a.m. 2 p.m.	6 56 S.	93 01	Collected dust off the deck. Pumice-stone floating in the water. At 2 p.m. dust still falling: large quantities of pumice floating past.
Brigantine *Airlie* (Capt. Knight)	Sept. 9	6 a.m. 2 p.m.	7 31 S.	103 11	Large quantities of lava. Passing through large quantities of lava.
French barque *Gipsy* (Capt. Martin)	„ 9	9 a.m.	4 57 S.	79 46 E. P.	Grand banc flottant de pierre-ponce pendant toute la journée, suivant le vent comme dans la mer de Sargosse.
French barque *Marie Alfred* (Capt. Brégeon)	„ 20	6 a.m.	7 02 S.	101 15	Nous passons dans des bancs successifs et très rapprochés de pierre-ponce.
Barque *Hottenburn* (Capt. Chichester)	Oct. 13	4 p.m.	Sunda Straits		Tremendous fields of pumice stopped the vessel.
	„ 14	4 a.m.	No obs.		Lots of pumice alongside.
	„ 15	midt.	7 19 S.	104 00	Passing large fields of pumice.
S.S. *Garonne*	„ 21	9·15 a.m.	10 15 S.	78 07	Passed through several fields of pumice-stone of various sizes. Some pieces that were picked up had barnacles nearly one inch long adhering to them.
S.S. *Countess of Errol* (Capt. Taylor)	„ 26	noon	7 01 S.	104 49	Vast quantities of pumice all round the ship.

Names of Vessels	Month and Day	Hours	Position at Noon		Remarks
			Lat.	Long.	
	1883			E.	
S.S. *Countess of Errol* —cont.	Oct. 27	8 a.m.	8° 44′ S.	102° 40′	Sailing through vast quantities of pumice.
Barque *Rollo* (Capt. Currie)	Nov. 15	6 a.m.	6 19 S.	88 55	Since daylight sailing through large quantities of pumice. At midnight still large quantities of pumice floating on water.
	,, 16	noon	8 04 S.	87 25	Still large quantities of pumice floating past.
	,, 17	noon	9 36 S.	85 46	,, ,, ,,
Barque *Eva Joshua*) (Capt. Florentin)	,, 28	8 a.m.	6 24 S.	62 25 E. P.	Sailing all day through floating pumice covered with barnacles.
French barque *Henriette* (Capt. A. de Lavit)	Dec. 2	5 a.m.	5 42 S.	86 47 E. P.	Au jour nous avons remarqué que nous étions environné de pierre-ponce. A 9 heures nous sommes toujours entouré de pierre-ponce.
	,, 3	5 a.m.	No obs.		Il y a encore de pierre-ponce.
	,, 4	6 a.m.	7 14 S.	87 32	Nous avons encore rencontré de pierre-ponce.
	,, 5	9 a.m.	8 44 S.	?	Nous recontrons encore beaucoup de pierre-ponce.
Barque *Ta Lee* (Capt. Stolzee)	,, 2	4 p.m.	6 07 S.	81 55	Passed a bank of pumice extending about twenty-five miles; some pieces about two feet square.
	,, 7	a.m.	8 59 S.	82 14	Still passing pumice-stone and a kind of ashes.
Ship *Shah Jehan* (Capt. Williams)	,, 9	6 a.m.	7 26 S.	84 58	Noticed the sea covered in streaks with what appeared to be pumice-stone in pieces and in powder; lowered the boat and picked up some; some of the stones covered with barnacles.
	,, 13	—	13 47 S.	82 00	Throughout the day the sea covered in streaks with some kind of lava and large-sized lumps of pumice-stone.
	,, 14	—	15 03 S.	81 42	Passed a great deal of pumice and lava this day.

Names of Vessels	Month and Day		Hours	Position at Noon		Remarks
				Lat.	Long.	
	1883				E.	
Ship *Shah Jehan*—cont.	Dec.	15	—	15° 30′ S.	80° 51′	Passed a lot of pumice and lava.
Ship *Invercauld* (Capt. Leslie)	"	12	8 a.m.	11 45 S.	87 09	Passed through a quantity of dust seemingly floating on the surface.
	"	14	10 a.m.	9 54 S.	87 56	Passed through a quantity of pumice-stone.
	"	15	a.m.	7 56 S.	89 32	Passed large quantities of pumice-stone.
Barque *Evelyn* (Capt. Stevenson)	"	20	noon	9 40 S.	88 11	Passing great quantities of pumice.
	"	21	?	7 30 S.	88 26	Still passing quantities of pumice.
Barque *May Queen* (Capt. Hugon)	"	28	—	2 14 N.	85 35	Une infinité de parcelles de roche brûlée sur l'eau.
	1884					
Sch. *Lord Tredegar* (Capt. Clarke)	Jan.	5	2 p.m.	6 35 S.	68 25	Passed through a quantity of lava.
	"	8	noon	12 12 S.	66 59	" " "
	"	9	—	14 56 S.	65 18	Passed through a great quantity of pumice to-day.
	"	10	noon	17 34 S.	63 04	" " "
French barque *Résolu* (Capt. Mouton)	"	8	p.m.	7 05 S.	81 41 E. P.	Traversé plusieurs bancs de pierre-ponce.
Barque *May Queen* (Capt. Hugon)	"	9	a.m.	7 00 S.	83 13	Une infinité de roche brûlée flottant.
	"	12	p.m.	11 23 S.	75 46	Une infinité de débris volcaniques.
Ship *Argomene* (Capt. H. Williams)	"	12	8 p.m.	7 51 S.	87 05	Passing through large quantities of pumice.
Ship *Roderick Dhu* (Capt. Boldchild)	"	13	4 p.m.	13 34 S.	90 50	Passing through large quantities of pumice.
	"	14	p.m.	9 25 S.	90 26	" " "
French barque *Eugénie* (Capt. A. Arnaud)	"	15	p.m.	6 14 S.	81 40	Beaucoup de pierre-ponce formant de lis allongé à l'ouest.
Barque *Star of Greece* (Capt. W. Legg)	"	21	7 a.m.	13 49 S.	85 45	Large quantities of pumice in separate streams from S.E. to N.W. At 6 p.m. still passing large quantities of pumice.
	"	22	2 a.m.	13 21 S.	86 06	The streams of pumice-stone stopped.
	"	23	midt.	10 45 S.	85 50	A large stream of pumice-stone.
Barque *Era Joshua* (Capt. Florentin)	"	22	p.m.	13 05 S.	64 20 E. P.	Sighted pumice-stone.
Sch. *Glenesk* (Capt. Feleng)	"	26	a.m.	3 19 S.	78 45 E. P.	Rencontré à chaque instant des bancs formés par des pierres-ponce.
Sch. *Mary Whitridge* (Capt. Howes)	Feb.	9	7 a.m.	9 41 S.	88 26	Passing lots of floating pumice-stone.

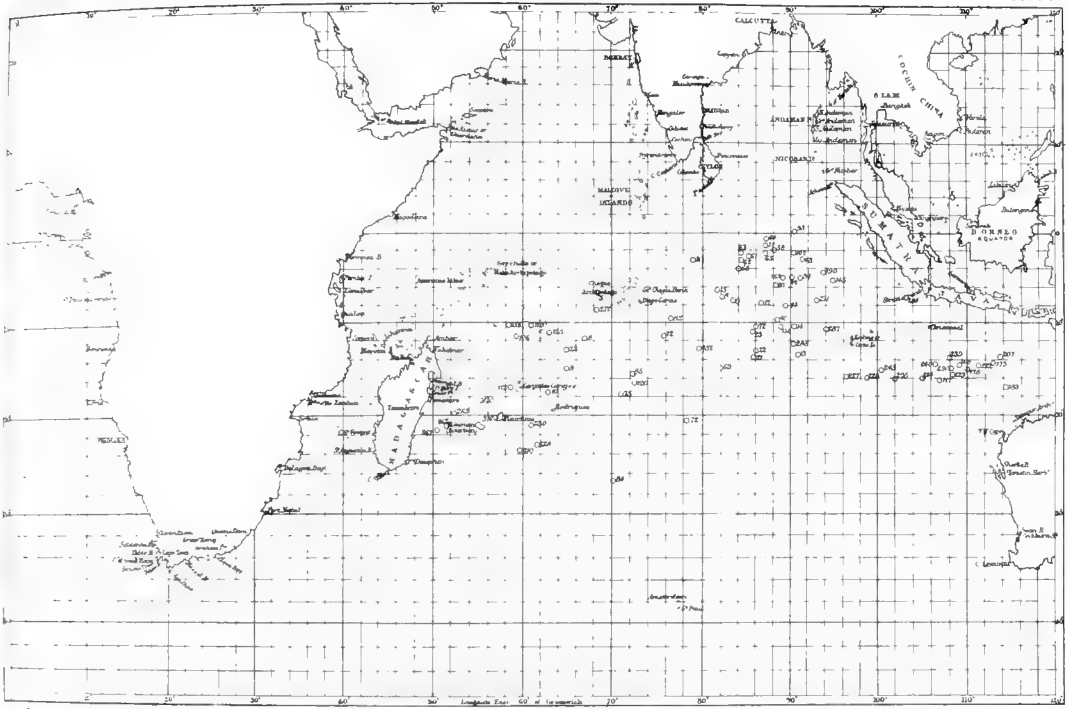
SEEN IN THE INDIAN OCEAN

Plate Va



c Dust was seen in the Indian Ocean in 1883-84.

CHART SHOWING WHERE AND WHEN PUMICE OR VOLCANIC DUST WAS SEEN IN THE INDIAN OCEAN FROM JAN. 1884 TO NOVEMBER 1884.



Illustrating Mr Meldrum's Tabular Statement of the Dates at which, and Localities where, Pumice or Volcanic Dust was seen in the Indian Ocean in 1883-84.

Names of Vessels	Month and Day	Hours	Position at Noon		Remarks
			Lat.	Long.	
	1884			E.	
Sch. *Mary Whitridge* —cont.	Feb. 10	5 a.m.	8° 11′ S.	89° 24′	Passing lots of floating pumice-stone.
	„ 11	5 a.m.	5 06 S.	90 11	„ „ „
	„ 12	2 a.m.	2 43 S.	91 26	Passing large fields of pumice.
Barque *County of Flint* (Capt. Rowland)	„ 26	—	1 27 S.	86 53	Great quantities of pumice, which appears to have been long in the water.
	„ 27	—	1 50 S.	87 48	Pumice-stone passing.
	March 1	4 a.m.	2 21 S.	85 21	Great quantities of pumice-stone in sight.
	„ 2	2 a.m.	2 40 S.	84 31	Great quantities of pumice passing.
	„ 3	2 p.m.	2 36 S.	84 10	„ „ „
	„ 5	3 a.m.	4 01 S.	83 57	„ „ „
		2 p.m.	—	—	„ „ „
Ship *Parthenope* (Capt. F. Gray)	„ 4	—	1 36 S.	87 21	Sea strewed with pumice-stone covered with barnacles.
	„ 5	—	2 14 S.	87 21	„ „ „
	„ 6	—	3 36 S.	88 04	„ „ „
	„ 10	—	5 52 S.	88 16	„ „ „
	„ 12	—	10 38 S.	86 09	Sea covered with lava and pumice 2 feet thick.
	„ 15	—	17 49 S.	70 40	Sea strewed with lava and pumice.
Ship *Kelvinside* (Capt. Kirkell)	„ 9	noon	14 40 S.	81 56	Since 7th been sailing through floating pumice in pieces from the size of a cocoanut to pieces almost like dust.
Barque *Excelsior* (Capt. F. Edgar)	„ 12	6 p.m.	20 27 S.	78 09	Great quantities of floating pumice.
Sch. *Iris* (Capt. Shaw)	„ 22	p.m.	9 35 S.	76 39	Passing vast quantities of pumice.
	„ 25	a.m.	15 33 S.	72 11	„ „ „
Sch. *Northern Bell* (Capt. L. Morris)	„ 24	p.m.	26 33 S.	70 00	For four hours passing a vast quantity of pumice-stone covered with barnacles.
Ship *Invercauld* (Capt. Leslie)	April 2	a.m.	00 06 S.	90 30	Passing through a quantity of pumice.
	„ 6	—	4 40 S.	91 13	During last five days passed through a quantity of pumice-stone, of a greenish colour and covered with barnacles and crabs.
Barque *Evelyn* (Capt. Stevenson)	„ 11	a.m.	2 10 S.	90 13	Passing quantities of pumice-stone.
Barque *Peggie Doy* (Capt. Hill)	„ 15	a.m.	11 34 S.	59 02	Passed large quantities of pumice.

Names of Vessels	Month and Day	Hours	Position at Noon Lat.	Position at Noon Long.	Remarks
	1884			E.	
Barque *Peggie Doy*—cont.	April 21	a.m.	16° 55′ S.	58° 22′	Passed quantities of pumice.
S.S. *Madagascar* (Capt. A. Vielle)	„ 29	p.m.	18 22 S.	54 56 E. P.	Several pieces of pumice floating alongside.
Ship *Knight Commander* (Capt. Bell)	„ 29	a.m.	16 38 S.	72 19	Passed through fields of pumice-stone and scoriæ.
Barque *Caller Ou* (Capt. Rae)	May 4	a.m.	11 07 S.	62 41	Sailing through quantities of lava.
Lugger *Success* (Capt. Hazel)	„ 4	—	10 16 S.	60 15 E. P.	Depuis plusieurs jours la mer est couverte de pierre et de sable volcanique d'une couleur jaunâtre.
Ship *Knight Companion* (Capt. Davis)	„ 15	a.m.	10 32 S.	88 53	Passing through quantities of pumice.
Barque *Iris* (Capt. Evans)	„ 24	p.m.	5 21 S.	94 44	A great quantity of floating pumice.
French barque *Louise Collet* (Capt. Beckman)	„ 31	a.m.	12 43 S.	79 09 E. P.	On rencontre toujours des pierres-ponce.
Brig *Flora* (Capt. Menton)	„ 31	p.m.	10 18 S.	58 09	Le capitaine tombe à la mer en pêchant des pierres-ponce.
Ship *Broomhall* (Capt. Grieve)	June 13	2 p.m.	5 29 S.	89 39	Passing through quantities of pumice covered with barnacles.
Brig *Rio Loge* (Capt. Lovett)	„ 17	noon	11 29 S.	126 29	Passed large quantities of pumice.
	„ 17	4 p.m.	—	—	„ „ „
	„ 23	6 a.m.	14 39 S.	113 36	„ „ „
	„ 23	6 p.m.	—	—	„ „ „
	„ 24	5 p.m.	15 16 S.	110 08	„ „ „
	„ 25	6 p.m.	16 07 S.	106 51	„ „ „
Sch. *Iris* (Capt. Shaw)	July 1	2 a.m.	17 08 S.	114 33	Passing vast quantities of pumice.
Ship *Reigate* (Capt. Ritchie)	„ 8	7 a.m.	4 25 S.	93 47	Passed through large quantities of pumice.
Barque *Northern Star* (Capt. Evans)	„ 25	4 a.m.	13 42 S.	113 42	Large quantities of pumice floating on the water.
	„ 26	4 a.m.	14 46 S.	109 43	„ „ „
Sch. *Catherine Marie* (Capt. Stubington)	„ 28	7 a.m.	23 36 S.	59 40	Passed through quantities of pumice varying in size from an orange to a walnut shell. Picked up some pieces covered with barnacles and limpets.
Barque *City of Tanjore* (Capt. Sinclair)	Aug. 9	4 p.m.	14 45 S.	111 20	Passed small pieces of pumice.
	„ 10	noon	15 28 S.	108 12	Sailing through large quantities of pumice floating in streaks like Gulf-weed.

Names of Vessels	Month and Day		Hours	Position at Noon		Remarks
				Lat.	Long.	
	1884				E.	
Barque *City of Tanjore*—cont.	Aug.	11	5 a.m.	16° 05′ S.	104° 53′	Still sailing through quantities of pumice. Passed a large spar in the water.
	„	12	8 a.m.	16 00 S.	101 56	Still sailing through pumice.
	„	13	4 p.m.	16 04 S.	99 05	„ „ „
	„	14	4 p.m.	16 06 S.	96 16	Less pumice to-day.
Sch. *Jasper* (Capt. Stannard)	„	15	a.m.	23 06 S.	61 47	Passed several pieces of floating pumice.
	„	17	a.m.	20 56 S.	61 01	„ „ „
Barque *Marion Neil* (Capt. Paterson)	„	26	8 a.m.	14 09 S.	108 06	A lot of pumice-stone floating past.
	„	27	6 a.m.	14 36 S.	106 39	„ „ „
	„	30	8 a.m.	15 19 S.	100 30	„ „ „
Barque *Jane Maria* (Capt. Griffiths)	Sept.	1	7.30 a.m. to noon	9 10 N.	112 11	Passed through a quantity of very small pumice-stone.
Sch. *Coleridge* (Capt. Marshall)	„	17	noon	21 15 S.	50 20	Several pieces of floating pumice.
	„	18	4 p.m.	20 39 S.	51 10	Passed large quantities of pumice which, apparently has been a long time in the water.
	„	19	noon	20 04 S.	52 24	„ „ „
Barque *Caller Ou* (Capt. Rae)	„	27	8 a.m.	7 20 S.	93 02	Much lava floating about.
S.S. *Castlebank* (Capt. Chevalier)	„	28	3 p.m.	8 39 S.	68 31	Passed through large quantities of pumice, which seems to have been a long time in the water.
Barque *Jane Maria* (Capt. Griffiths)	Oct.	10	p.m.	6 58 S.	102 54	Passed a large quantity of floating pumice.
	„	13	3.30 p.m.	10 44 S.	93 57	Passed a large quantity of very small pumice.
	„	14	5 a.m.	12 33 S.	90 19	„ „ „
	„	14	5 p.m.	—	—	Large and small pieces of pumice seen frequently during the afternoon.
French barque *France Chérie* (Capt. Lavary)	„	16	—	15 09 S.	107 39 E. P.	Depuis plusieurs jours la mer est couverte de pierre-ponce.
	Nov.	11	—	20 21 S.	56 35 E. P.	J'ai parcouru environ une étendue de 1,200 milles par latitude sud où j'ai rencontré beaucoup de pierre-ponce.

List of Works on the Geology, Mineralogy, and Palæontology of Staffordshire, Worcestershire, and Warwickshire.

By WILLIAM WHITAKER, *B.A., F.G.S., Assoc.Inst.C.E.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

1. INDEX OF AUTHORS, WITH THE NUMBERS PREFIXED TO THEIR WORKS.

2. STAFFORDSHIRE.

Geological Survey Publications.

Maps. Scale an inch to a mile.

(1) Sheet 54, N.W. (small part at N.). By A. C. Ramsay, J. B. Jukes, H. H. Howell, and E. Hull, 1852. New Ed. 1855.

(2) Sheet 55, N.E. (small part at N.E.) By J. Phillips, W. T. Aveline, and H. H. Howell. 1853. New Ed. 1855.

(3) Sheet 61, S.E. (E. edge). By W. T. Aveline and E. Hull, 1852. New Ed. 1855.

(4) Sheet 61, N.E. (N.E. corner and a little at S.E.). By W. T. Aveline, E. Hull, and A. C. Ramsay. ? no date. Reissued 1855.

(5) Sheet 62, S.W. (all but S. and S.E. parts.—Bilston, Dudley, Walsall, Wednesbury, Wolverhampton). By A. C. Ramsay, J. B. Jukes, and E. Hull. 1852. New Eds. in 1855 and 1858.

(6) Sheet 62, S.E. (at N.W. and S.W.—Birmingham). By A. C. Ramsay and H. H. Howell. 1855 ? New Ed. in 1868.

(7) Sheet 62, N.W. (Brewood, Cannock, Penkridge, and Rugeley). By J. B. Jukes, E. Hull, and H. H. Howell. 1852. New Eds. 1855, 1858, 1859, partly by A. C. Ramsay.

(8) Sheet 62, N.E. (all but N.E. and S.E. corners. Tamworth and Litchfield). By A. C. Ramsay and H. H. Howell. 1856. New Ed. 1868.

(9) Sheet 63, N.W. (very small piece on W.). By H. H. Howell and E. Hull, 1855.

(10) Sheet 71, S.W. (very small piece on W.). By E. Hull, 1855.

(11) Sheet 72, S.W. (Stafford, Stone). By E. Hull, 1852. New Ed. 1855.

(12) Sheet 72, S.E. (all but N.E. part and S.E. corner.—Abbot's Bromley, Burton, Uttoxeter). By H. H. Howell, 1852.

(13) Sheet 72, N.W. (Cheadle, Hanley, Newcastle, Stoke). By W. W. Smyth and E. Hull. 1857. Additional information, by A. H. Green, 1868.

(14) Sheet 72, N.E. (W. part). By J. Phillips, A. C. Ramsay, and E. Hull. 1852. New Ed. 1855. Additions, by A. H. Green, 1878.

(15) Sheet 73, S.E. (E. part.—Eccleshall). By A. R. Selwyn and E. Hull. 1855.

(16) Sheet 73, N.E. (at E. and S.E.). By W. W. Smyth and E. Hull. 1857.

(17) Sheet 81, S.W. (S.E. part.—Leek). By A. H. GREEN, 1864.

(18) Sheet 81, S.E. (S.W. corner. Longnor). By J. PHILLIPS and W. W. SMYTH, 1852. Revisions, by A. H. GREEN and J. R. DAKYNS, 1866.

Horizontal Sections. Scale six inches to a mile.

(19) Sheet 18 (top line). Section from the Red Marl plain of Cheshire across the Lower Carboniferous rocks of North Staffordshire. . . . By J. PHILLIPS and A. H. GREEN. New edition, 1866. (Ed. 1 does not refer to Staffordshire.)

(20) Sheet 23. South Staffordshire. Section No. 1, North and South, from Bellbroughton, through the Clent Hills, Dudley, Bentley, Norton, Beaudesert, and Brereton, to the neighbourhood of Rugeley. No. 4 . . . across the extreme northern end of the S. Staffordshire coal-field. No. 5 . . . from Wyrley to Pelsall. By J. B. JUKES. 1853. Revised 1865.

(21) Sheet 24. South Staffordshire. Section No. 2 . . . from Lappal, by Rowley, Dudley, and Sedgley, to Compton. . . . No. 3, North and South, through Hagley Park, Brickley Hill, Barrow Hill, Turners Hill and Lidget Hill. No. 6, East and West. Through Sedgley, Darlaston and Walsall to Barr Beacon. By J. B. JUKES. ? date. Additions and corrections, by A. C. RAMSAY, H. H. HOWELL, and E. HULL, 1856. Revised 1865.

(22) Sheet 25. South Staffordshire. Section No. 7, East and West through Kingswinford, Dudley, and Westbromwich. No. 8, East and West through Wordesley, Brierley Hill, Rowley, and Langley. No. 9 East and West from Stourbridge by Cradley, the Hawn, Mucklowhill and the Quinton. No. 10, North and South, Through Frankley Beeches, Hasbury, Hawn, . . . to the Old Lion Colliery. By J. B. JUKES, 1853. Additions, by A. C. RAMSAY, H. H. HOWELL, and E. HULL, 1856. Revised 1865.

(23) Sheet 41. Section from South West to North East across . . . New Red Sandstone, Permian, the North Staffordshire Coalfield and Carboniferous Limestone, through Norton, Whitmore Heath, Longton to Waterfall Low. By E. HULL and A. H. GREEN, 1857.

(24) Sheet 42. Section from West to East across the New Red Sandstone; the North Staffordshire Coalfield . . . through Talk, Endon & Parwich. By E. HULL and A. H. GREEN, 1857. Revisions 1868.

(25) Sheet 45. No. 1. Section from West to East across the . . . New Red Sandstone, near . . . Wrottesley Park, and Bushbury, & the S. Staffordshire Coalfield, by Essington Wood, and Pelsall Wood, to the Lichfield Road. By E. HULL. 1858.

(26) Sheet 49. Section 1. From Barr Beacon . . . (small piece only). By H. H. HOWELL, 1858.

(27) Sheet 54. No. 1. Section from N.W. to S.E. . . . to Baggeridge Wood, S. of Wolverhampton, Staffordshire. No. 2. Section from West to East . . . to Oreton Hill, South Staffordshire, through the . . . New Red Sandstone. By E. HULL. 1858.

(28) Sheet 57. No. 1. Section from S.W. to N.E. across the New Red Sandstone and Permian Rocks, N. of Stone, Fulford & Drayeott, the Coalfield of Cheadle, to the Carboniferous Limestone of Throwley Low, North Staffordshire. No. 2. Section from S. to N. across the New Red Sandstone of Rugeley, North Staffordshire, the New Red Marl and

Lias, of Bagot Park; to the Carboniferous Limestone of the Weaver Hills. By E. HULL and A. H. GREEN. 1859.

(29) Sheet 58. Section No. 2. From West to East . . . across . . . the Permian Rocks and New Red Sandstone, near Shiffnal and Brewood, to the Western border of the S. Staffordshire Coal-field, S. of Cannock. By E. HULL and H. BAUERMAN. 1860.

Vertical Sections. Scale 40 feet to an inch.

(30–32) Sheets 16–18. Vertical Sections in the South Staffordshire Coal-field. By J. B. JUKES, 1853.

(33) Sheet 26. Pit Sections from the South Staffordshire Coal Field. By J. B. JUKES, 1860.

Memoirs, 8vo, London.

(34) On the Geology of the South Staffordshire Coalfield. By J. B. JUKES. Records of the School of Mines, Part ii. Pp. 149–348 (1853) Ed. 2, as a separate Memoir, 'The South Staffordshire Coal-field,' Pp. xiv, 241 (1859).

(35) The Triassic and Permian Rocks of the Midland Counties of England. By E. HULL. Pp. x, 127 (1869).

(36) The Iron Ores of Great Britain. Part ii. The Iron Ores of South Staffordshire. By J. B. JUKES, J. SPILLER, A. DICK, and C. TOOKEY. Pp. iv, 99–164 (1858).

(37) Do: Part IV. Iron Ores of . . . North Staffordshire. Pp. 255–296. By W. W. SMYTH, A. DICK, J. SPILLER, and J. W. SALTER (Notes on the Fossils). (1862).

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To the end of 1873, after which year the GEOLOGICAL RECORD gives an account of works on English Geology.

1679 and 1686.

(38) PLOTT, DR. R. Natural History of Staffordshire. Fol. *Oxon.*

1683.

(39) PLOTT, DR. R. The Contents of some Letters from Two learned and curious Observers in Staffordshire, concerning the Sand found in the Brine of the Saltworks of that Country. *Phil. Trans.* vol. xiii. no. 145, p. 96.

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(40) LISTER, DR. M. Certain Observations of the Midland Salt-Springs of Worcester-shire, Stafford-shire, and Cheshire. *Phil. Trans.* vol. xiv. No. 156, p. 489.

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(41) BELLERS, F. A Description of the several Strata of Earth, Stone, Coal, &c., found in a Coal-Pit at the West End of Dudley in Staffordshire. To which is added a Table of the Specifick Gravity of each Stratum. *Phil. Trans.* vol. xxvii. No. 336, p. 541.

1740.

(42) SHORT, DR. T. An Essay Towards A Natural, Experimental, and Medicinal History of the Principle Mineral Waters of . . . Staffordshire, Warwickshire, Worcestershire, &c. 4to. *Sheffield.*

1751.

(43) LYTTELTON, REV. DR. C. A Letter concerning a nondescript petrified Insect. [Dudley]. *Phil. Trans.* vol. xlvi. no. 496, p. 598. With 'Some farther Account of the before-mentioned Dudley Fossil,' by the Editor (Dr. C. MORTIMER), p. 600.

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(44) WITHERING, DR. W. Experiments upon the different Kinds of Marle found in Staffordshire. *Phil. Trans.* vol. lxiii. part 1, p. 161.

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(45) JARS, M. G. Voyages Metallurgiques, tome i. (p. 253). 4to. *Lyons.*

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(47) WITHERING [DR.] W. An Analysis of Two Mineral Substances, viz. the Rowley rag-stone and the Toad-stone. *Phil. Trans.* vol. lxxii. part 2, p. 327.

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(49) WATT, G. Observations on Basalt. (Analysis of Rowley Rag.) *Journ. Nat. Phil. Chem. Arts*, ser. 2, vol. x. pp. 113, 165.

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(50) MUSHET, D. Analysis of various kinds of Pit-coal. *Phil. Mag.* vol. xxxii. p. 140.

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(51) FAREY, J. Observations on a late Paper by Dr. W. Richardson, respecting the basaltic District in the North of Ireland, and on the Geological Facts thence deducible; in conjunction with others observable in Derbyshire and other English Counties . . . &c. . . . *Phil. Mag.* vol. xxxiii. p. 257.

1810.

(52) FAREY, J. A List of about Five Hundred Collieries in and near to Derbyshire. *Phil. Mag.* vol. xxxv. p. 431.

1811.

(53) FAREY, J. A List of about 280 Mines of Lead,—some with Zinc, &c. &c. in and near to Derbyshire. *Phil. Mag.* vol. xxxvii. p. 106.

(54) —— A List of about 700 Hills and Eminences in and near to Derbyshire, with the Stratum which occupies the top of each, and other Particulars. *Ibid.* pp. 161, 443.

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(55) FAREY, J. An Account of the Great Derbyshire Denudation. *Phil. Mag.* vol. xxxix. p. 26.

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(56) AIKIN, A. Some observations on a Bed of Trap occurring in the Colliery of Birch Hill near Walsall in Staffordshire. *Trans. Geol. Soc.* vol. iii. p. 251.

(57) THOMSON, DR. T. Geological Sketch of the Country round Birmingham. *Ann. Phil.* vol. viii. p. 161.

1817.

(58) PITT, W. Topographical History of Staffordshire, including its Agriculture, Mines and Manufactures. 8vo.

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(61) YATES, REV. J. Account of a Variety of Argillaceous Limestone, found in connexion with the Iron-stone of Staffordshire. *Trans. Geol. Soc.* vol. v. p. 375.

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(66) —— Notice of some Fragments of Orthoceras annularis and striata, found in the Barr Limestone in Warwickshire. With a Note by J. D. C. SOWERBY. *Ibid.* p. 231.

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(70) MURCHISON, [SIR] R. I. A general view of the new red sandstone series, in the counties of Salop, Stafford, Worcester, and Gloucester. *Ibid.* no. 38, p. 115.

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(72) WARD, DR. O. Lectures on Geology, in illustration of the Strata in the Neighbourhood of Birmingham. *Analyst*, vol. ii. p. 240.

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(80) TOOKE, A. W. The Mineral Topography of Great Britain, (Staffordshire, p. 50; Worcestershire, p. 52). *Mining Review*, No. 9, p. 39.

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(84) ANON. On several new species of Encrinite and Hypanthocrinite from the neighbourhood of Dudley. *Geologist*, p. 25.

(85) DAWES, J. S. On the Occurrence of Vegetable Remains, supposed to be Marine, in the New Red Sandstone. *Rep. Brit. Assoc. for* 1842, *Sections*, p. 47.

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(88) BECKETT, H. On a Fossil Forest in the Parkfield Colliery near Wolverhampton. *Proc. Geol. Soc.* vol. iv. p. 287; and *Quart. Journ. Geol. Soc.* vol. i. p. 41 (1845).

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(100) BAKER, T. Practical Survey of the Geology, Mineralogy, &c. . . . of the District of Dudley. 8vo. *Birmingham.*

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Nos. 1, 2, 3, 5, 6, 20, 22, 34, 35 of the Staffordshire List refer also to Worcestershire.

Maps. Scale an inch to a mile.

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(255) Sheet 44. (N.W. part. Evesham, Upton.) By H. H. HOWELL and [PROF.] E. HULL, 1856.

(256) Sheet 54, S.W. (Droitwich, Pershore, Worcester.) By H. H. HOWELL, 1854.

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(258) Sheet 54, N.W. (Bromsgrove, Droitwich). By [SIR] A. C. RAMSAY, [PROF.] J. B. JUKES, H. H. HOWELL, and [PROF.] E. HULL. 1852. New Ed. 1855.

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(260) Sheet 55, S.W. (little bit at N.E. corner.) By W. T. AVELINE and A. R. SELWYN. 1850.

(261) Sheet 55, S.E. (E. half.) By [PROF.] J. PHILLIPS, W. T. AVELINE, A. R. SELWYN, and H. H. HOWELL. 1853. New Ed. 1855.

(262) Sheet 55, N.W. (little bit at S.E. corner. Tenbury). By W. T. AVELINE. 1850 and 1855.

(263) Sheet 55, N.E. (Bewdley, Kidderminster, Stourport.) By [PROF.] J. PHILLIPS, W. T. AVELINE, and H. H. HOWELL, 1853. New Ed. 1855.

Horizontal Sections. Scale 6 inches to a mile.

(264) Sheet 13. (3. Berrow Hill; 4. N. point of Swinyard Hill; 5. Herefordshire Beacon; 6. The Wych.) By [SIR] A. C. RAMSAY and [PROF.] J. PHILLIPS.

(265) Sheet 50. (Section from Neen Soller, near Cleobury Mortimer.) Worcestershire across the Forest of Wyre Coalfield, through the intervening Permian and New Red Sandstone strata. . . . By H. H. HOWELL, 1858.

(266) Sheet 59. By [PROF.] E. HULL. 1860.

Vertical Section. Scale 40 feet to an inch.

(267) Sheet 15. Section from the Old Red Sandstone through the Silurian Strata, to the Syenitic Rocks of the Malvern Hills. By PROF. J. PHILLIPS.

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(269) The Geology of the Country around Cheltenham. (Sheet 44.) By [PROF.] E. HULL. 1857.

(270) Explanation of Horizontal Sections. (Sheets 50 & 51.) 1859.

(271) Description of Horizontal Section, Sheet 59. By [PROF.] E. HULL. 1861.

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4. WARWICKSHIRE.

A Warwickshire List was published in *Rep. Rugby School Nat. Hist. Soc.* for 1872, pp. 66–76; but it may fairly be reproduced here (rearranged and with a few additions), in order to complete the geologic bibliography of the district around Birmingham.

GEOLOGICAL SURVEY PUBLICATIONS.

Nos. 5, 6, 9, 26, 255, 256, 257, 259, 265 of the Staffordshire and Worcestershire Lists refer also to Warwickshire.

Maps. Scale an inch to a mile.

(401) Sheet 45, N.W. (N.W. corner). By H. BAUERMAN and T. R. POLWHELE. 1859.

(402) Sheet 53, S.W. (Kington, Southam.) By H. H. Howell. 1856.

(403) Sheet 53, N.W. (Coventry, Rugby, Warwick.) By [Sir] A. C. Ramsay and H. H. Howell. 1854.

(404) Sheet 53, N.E. (W. edge, Rugby.) By H. H. Howell. 1859.

(405) Sheet 63, S.W. (Atherstone, Nuneaton.) By H. H. Howell. 1854.

(406) Sheet 63, S.E. (small piece at S.W. corner). By [Sir] A. C. Ramsay and H. H. Howell. 1854.

Horizontal Sections. Scale 6 inches to a mile.

(407) Sheet 48. (From Lazy Hill, across the Warwickshire Coal-field to Wysall.) By H. H. Howell. 1856.

(408) Sheet 51 (part). Section through . . . the Warwickshire Coal Field, &c. By H. H. Howell. 1858.

Vertical Section. Scale 40 feet to an inch.

(409) Sheet 21. Warwickshire Coalfield. By H. H. Howell. 1857.

Memoir, 8vo. *London.*

(410) The Geology of the Warwickshire Coal-field and the Permian Rocks and Trias of the Surrounding District. By H. H. Howell. 1859.

Books, Papers, etc., chronologically arranged.

Nos. 42, 54, 57, 65, 66, 67, 72, 74, 75, 85, 90, 124, 134, 137, 143, 172, 241, 282, 283, 288, 309, 311, 313, 316, 317, 322, 342, 343, 354, 359, 361, 369, 378, 384, 386, 389, 392 of the Staffordshire and Worcestershire Lists refer also to Warwickshire.

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(412) Allen, B. The Natural History of the Chalybeat and Purging Waters of England. . . . 8vo. *Lond.*

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(413) Lambe, W. An Analysis of the Waters of two Mineral Springs at Lemington Priors, near Warwick; including Experiments tending to elucidate the Origin of the Muriatic Acid. *Phil. Mag.* vol. i. pp. 255, 350.

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(414) Dalton, S. (Extraordinary Bones found at Rugby.) *Monthly Mag.* vol. xxxiv. no. 234, p. 407.

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(415) Parkes, S. Notice on the Black Oxide of Manganese of Warwickshire. *Trans. Geol. Soc.* ser. 2, vol. i. p. 168.

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(416) Buckland, Rev. Dr. W. Reliquiæ Diluvianæ; or, Observations on the Organic Remains contained in Caves, Fissures, and Diluvial Gravel, and on other Geological Phenomena, attesting the Action of an Universal Deluge. (Warwick, pp. 176, 248.) 4to. *Lond.*

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(417) GRIMES, R. Observations on the Flints of Warwickshire (Roy. Soc.) *Edin. Journ. Sci.* vol. iii. p. 77.

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(418) CUMBERLAND, G. Some Account of the Order in which the Fossil Saurians were discovered. *Quart. Journ. Sci. Lit. Art*, p. 345.

(419) PHILLIPS, R. On a new Compound of Oxygen and Manganese; with Remarks on Dr. Turner's Memoir on the Oxides of that Metal. *Phil. Mag.* ser. 2, vol. v. p. 209.

(420) —— On the Oxides of Manganese. *Ibid.* vol. vi. p. 281.

(421) TURNER, PROF. E. Remarks on Mr. Phillips' Essay on Manganese. *Ibid.* vol. v. p. 254.

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(422) DAUBENY, DR. C. Memoir on the occurrence of Iodine and Bromine in certain Mineral Waters of South Britain. (Warwick, pp. 234, 235.) *Phil. Trans.* vol. cxx. p. 233.

(423) SHARPE, D. Description of a New Species of Ichthyosaurus. *Proc. Geol. Soc.* vol. i. no. 16, p. 221.

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(424) JUKES, F. Observations on the Diluvial Gravel in the Neighbourhood of Birmingham. *Mag. Nat. Hist.* vol. iv. p. 372.

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(425) GREAVES, J. A Fossilised Fish and Ichthyosaurus found in a Stone Quarry near Stratford-upon-Avon. *Mag. Nat. Hist.* vol. v. p. 549.

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(429) GOOCH, T. L. Account of a Toad found alive imbedded in a Solid Mass of New Red Sandstone. *Rep. Brit. Assoc. for* 1835, *Sections*, p. 72.

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(431) —— On the occurrence of Keuper Sandstone in the upper region of the New Red Sandstone formation or Poikilitic system in England and Wales. *Ibid.* p. 453.

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(467) BRODIE, REV. P. B. Note on Hyperodapedon from Coton End, Warwick, in *Address to Warwick Nat. Hist. Archæol. Soc.*

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(478) WILSON, J. M. On the Victoria [Lime] Works. *Rep. Rugby School Nat. Hist. Soc.* for 1868, p. 9.

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(480) ANON. (Meetings at Bromsgrove and Lutterworth.) *Proc. Warwick Nat. Archæol. Field Club*, pp. 24, 31. See also 35 *Ann. Rep. Warwick Nat. Hist. Archæol. Soc.* pp. 25, 27. (1871.)

(481) BRODIE, REV. P. B. On the Geology of Warwickshire. 34 *Ann. Rep. Warwick Nat. Archæol. Soc.* p. 10.

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(487) ARMITAGE, J. Localities [of fossils] new to the List. *Rep. Rugby School Nat. Hist. Soc.* for 1870, p. 45.

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(488) ALLPORT, S. On the 'Palæontology of the District.' *Proc. Birmingham Nat. Hist. Soc.* no. 2, p. 31.

(489) ANON. Excursion to Warwickshire. *Proc. Geol. Assoc.* vol. ii. no. 7, p. 284.

(490) WILSON, J. M. Note on a Boulder lately discovered in Cosford Valley and a Conglomerate Boulder in Brownsover. *Rep. Rugby School Nat. Hist. Soc.* for 1871, p. 19.

(491) —— Note on a newly-discovered Oolitic Drift at Brownsover. *Ibid.* p. 20.

(492) —— Catalogue of Local Fossils in the Museum. *Ibid.* p. 55.

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(496) The Birmingham Saturday Half-Holiday Guide. Fossils by S. Allport. Geology by C. J. Woodward. 8vo. *Birmingham.*

On Slaty Cleavage and Allied Rock-Structures, with special reference to the Mechanical Theories of their Origin. By Alfred Harker, *M.A., F.G.S.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

I. *Introductory and Historical.*

The following paper is intended to deal in a comprehensive, though far from exhaustive, manner with the main phenomena of the cleavage structure in slate-rock, the received views of the origin and significance of these phenomena, and the relations existing between slaty cleavage and various allied rock-structures. It may be regarded as to some extent supplementary to the Report on Cleavage and Foliation presented to the British Association at the Cheltenham meeting in 1856 by the late Professor John Phillips;[1] and accordingly a few words seem to be called for in justification.

The facts so ably summarised by Professor Phillips were much less complete than those now at our disposal, and although they were perhaps sufficient in 1856 to establish on a firm basis the mechanical theories of slaty cleavage which had been already put forward by Messrs. Sharpe and Sorby, it could not be said that such theories had obtained anything like universal acceptance. Indeed Professor Phillips had in contemplation[2] a further report, in which the 'mechanical pressure' which these authors advocate' was to be 'placed in comparison with the crystalline polarity, formerly advanced by Professor Sedgwick,' and in which 'Mr. Fox's ingenious imitation of slaty cleavage by electrical currents' was also to receive attention. Following the tendency of more recent speculations, I propose to discuss the subject of slaty cleavage from a purely mechanical standpoint. Such an investigation will involve considering the relations of cleavage to contortion, to faulting, to jointing, and to foliation, subjects which had received but little notice at the date of Professor Phillips' report, but some of which are now recognised as among the foremost questions of geology.

Slaty cleavage may be defined as a superinduced tendency in a rock to split in a definite direction more readily than in other directions, such direction of splitting being independent of the planes of deposition in a sedimentary rock. In the classical paper of Professor Sedgwick,[3] referred to below, the following passage occurs: 'Besides the planes of cleavage, we may often find in large slate quarries one or more sets of cross joints, which, combined with the cleavage, divide the rock into rhombohedral solids. Should any one assert that this subdivision of slate rocks into rhombohedral solids implies three planes of cleavage, we might reply,

[1] *British Association Report*, 1856, p. 369. 'Report on Cleavage and Foliation in Rocks, and on the Theoretical Explanations of these Phenomena. Part I.'

[2] *Op. cit.*, p. 392.

[3] *Geol. Trans.*, 2nd ser., vol. iii. p. 473, 1835.

that such solids are not capable of *indefinite* subdivision into similar solids, except in one direction, viz., that of true cleavage.' The distinction here stated between true slaty cleavage and mere jointing is fundamental: slaty cleavage, like the crystalline cleavage of minerals, is a property of a definite *direction*, jointing a property of definite planes in the rock. If a rock-mass will split along a certain plane owing to a true slaty cleavage structure, it will split with equal readiness along any other plane parallel to the first; but although parallel joints may occur in a rock at very small distances apart, there is no special tendency in the parts of the rock between two successive joints to split parallel to them. Moreover, cleavage planes are merely surfaces of weakness, not of actual discontinuity, in the rock in which they occur; while, although secret or 'close' joints are not uncommon in some kinds of rocks, the structural planes properly known as joints are usually actual fissures, which may, however, be of very minute width.

The structure of slaty cleavage, to which the above remarks are strictly applicable, is typically exemplified in ordinary roofing-slate: in some other rocks we find a passage from the true cleavage structure to a system of close parallel planes of discontinuity (which, however, are not to be with propriety regarded as joints), while, on the other hand, it is difficult to discriminate the cleavage of slates from the *schistosité* of certain schists.

The words *clivage* and *Transversalschieferung*, when strictly appropriated,[1] are used in nearly the same sense as that in which we have defined cleavage: the first-named term is, however, employed by many writers with reference to structures which we should describe as jointing.

It seems desirable, if possible, to limit the name *slate* to rocks which exhibit the true cleavage-structure, although this restriction has not always been observed.

Confining our attention for the present to true slaty cleavage, it will be convenient to summarise at the outset the information that had been obtained on that subject prior to Professor Phillips' Report in 1856.

It is a matter of no small wonder that the fundamental difference of cleavage planes from surfaces of original deposition should have met with such tardy recognition at the hands of geologists in general. In North Wales, for instance, where some of the quarries have been worked for at least six centuries,[2] the cleavage-planes are often seen to cut at high angles across alternating bands of different lithological characters, which clearly indicate the original bedding of the rocks. The names of Otley,[3] MacCulloch,[4] and Phillips may be mentioned as among the first to recognise slaty cleavage as a distinct phenomenon. The scientific study of the structure must, however, be considered as dating from Prof. Sedgwick's paper 'On the Structure of Large Mineral Masses,'[5] read before the Geological Society of London in 1835. In this valuable contribution to physical geology the author insisted anew upon the distinction between cleavage and stratification, and pointed out clearly for the first time how the former structure differs from jointing; he showed that cleavage-planes

[1] *E.g.* Heim: *Untersuchungen über den Mechanismus der Gebirgsbildung*, Bd. ii. s. 53, 59; 1878, Basel.

[2] Davies, *Slate and Slate Quarrying*, chap. xxii., 2nd ed., 1880, London.

[3] *Kirkby Lonsdale Magazine*, 1820. 'Concise Description of the English Lakes,' 1823. Keswick.

[4] *Western Isles of Scotland*, vol. iii. p. 33, and pl. xxii. fig. 6, 1819. *Journ. Roy. Inst.*, 1825. *System of Geology*, vol. ii. 1831.

[5] *Trans. Geol. Soc.*, 2nd ser. vol. iii. p. 461, 1835.

may cut the bedding at any angle, according to the varying dips and contortions of the latter; he stated that they are much more regular in their arrangement than the bedding, maintaining their straight course throughout large tracts of country, and their dip changing very gradually as we cross successive planes; finally he laid down, as the result of his own researches in districts of slate-rocks, the important law, that 'where the cleavage is well developed in a thick mass of slate-rock, the *strike* of the cleavage is nearly coincident with the strike of the beds.'[1]

This last statement was modified by Professor Phillips, Dr. Darwin,[2] and Mr. Sharpe, who replaced it by the law, that the strike of the cleavage planes in a district is 'parallel to the main axes of elevation,' and not *necessarily* with the strike of the beds at any given locality. In this form the law was borne out by the researches of field-geologists[3] in all parts of the world where slate-rocks are met with. The law as enunciated by Professor Sedgwick has many exceptions, as he himself was the first to remark.

The alleged second direction of cleavage in certain slates, at right angles to the chief cleavage, as stated by Mr. D. Sharpe,[4] and subsequently by Professor Sedgwick[5] and others, is a point to be discussed below.

The next advance was the observation that the fossils associated with cleaved rocks are commonly more or less distorted in form, and that the mode of distortion is related to the direction of the cleavage-planes in the rock. This fact was first brought into notice by Professor Phillips,[6] but its significance was only subsequently made clear by Mr. Sharpe.[7] The latter geologist drew the conclusion that rocks affected by slaty cleavage have suffered a compression of their mass in a direction everywhere perpendicular to the plane of cleavage, and an expansion in the direction of cleavage-dip. The numerical results of Professor Haughton,[8] merely mentioned by Professor Phillips in an addendum, confirmed at least the former of these conclusions.

Messrs. Sharpe[9] and Sorby[10] showed that the form and arrangement of the fragments, both macro- and micro-scopic, which compose the mass of a cleaved rock, agree in every respect with the kind of distortion supposed, and made various other observations having the same bearing.

Finally, as regards the theories of slaty cleavage, Bakewell[11] and most of the earlier investigators considered the structure to be 'the effect of crystallisation'; MacCulloch[12] supposed it to be the result of 'concretionary action'; Professor Sedgwick[13] himself ascribed it to 'crystalline

[1] *Loc. cit.* p. 473. [2] *Geological Observations in South America*, p. 163, 1846.

[3] Darwin, Forbes, Harkness, Hopkins, Jukes, Murchison, Phillips, Ramsay, Rogers, Sedgwick, Sharpe, &c. [4] *Quart. Journ. Geol. Soc.*, vol. v. p. 114, 1849.

[5] *Synopsis of British Palæozoic Rocks*, Introd. p. xxxv., 1855. London and Cambridge.

[6] *Brit. Assoc. Rep.*, 1843, Trans. sec. p. 61.

[7] *Quart. Journ. Geol. Soc.*, vol. iii. p. 74, 1847.

[8] *Phil. Mag.* 4th ser., vol. xii. p. 409 (1856).

[9] *Quart. Journ. Geol. Soc.*, vol. v. p. 112 (1849).

[10] *Edinb. New Phil. Journ.*, vol. lv. p. 137 (1853). *Phil. Mag.*, 4th ser., vol. xi. p. 20 (1856).

[11] *Introduction to Geology*, p. 86 (1813).

[12] *Western Isles of Scotland*, vol. iii. p. 33 (1819). *Journ. Roy. Inst.* (1825). *System of Geology*, vol. ii. (1831).

[13] *Geol. Trans.*, 2nd ser., vol. iii. p. 477 (1835). *Synops. Brit. Pal. Rocks*, Introd. (1855). Cf. Professor H. D. Rogers, *Trans. Roy. Soc. Edinb.*, vol. xxi. p. 464 (1856).

and polar forces acting on the whole mass simultaneously, in given directions, and with adequate power.' Sir H. De la Beche[1] invoked the agency of electric currents and terrestrial magnetism, and cited in confirmation of this theory the experiments of Messrs. R. W. Fox[2] and R. Hunt.[3] Mr. Hopkins,[4] too, endeavoured to show a connection between cleavage and 'magnetic currents.' Dr. Charles Darwin,[5] whose views will be further referred to, was led to suspect 'that the planes of cleavage and foliation are intimately connected with the planes of different tension, to which the area was long subjected, *after* the main fissures or axes of upheavement had been formed, but before the final consolidation of the mass and the total cessation of all molecular movement.' The mechanical theory gained ground slowly, geologists being apparently reluctant to admit so simple an explanation of the phenomena. Mr. J. Beete Jukes,[6] for example, generalising from his observations in Newfoundland, wrote thus: 'The same causes which gave their prevalent and general direction to the mechanical forces by which the rocks were elevated from their original position, and their strike and dip produced, likewise determined the direction in which those forces should act (whatever they were), which produced the cleavage.' Mr. Sharpe[7] in his first paper on slaty cleavage, while admitting the action of pressure in the production of cleavage, declined to regard it as the sole agent concerned, and considered that heat may have had some share in the process; in his second paper, however, he had apparently arrived at a purely mechanical theory. But it still remained for Mr. Sorby[8] to show that all the main facts connected with slaty cleavage are explicable as the effects of a distortion of the mass of the rock consequent upon lateral compression. This theory was strengthened by the synthetic experiments of Mr. Sorby and Professor Tyndall,[9] in which a fissile structure resembling cleavage was artificially produced in various plastic substances by the agency of lateral pressure alone.

II. *The Mechanical Theory of Slaty Cleavage: the Distortion of Cleaved Rocks.*

It will be convenient at this point to put forward briefly the views of those geologists who have offered explanations of slaty cleavage founded solely on mechanical principles. These theories, however complete in themselves, are to be regarded not as the end of the investigation but rather as important landmarks by the way; for they are applicable only to the slaty cleavage structure proper in its various degrees of perfection, and there may even appear reasons for doubting whether the whole truth, even as regards roofing-slates and cleaved limestones, can always be expressed by a *purely* mechanical theory, in the sense implied here.

[1] *Report on the Geology of Cornwall, &c.*, p. 281 (1839), &c.
[2] *Reports of Cornwall Polytechnic Soc.*, 1837, pp. 20, 21, 68, 69. Cf. Phillips, *Treatise on Geology*, vol. ii. p. 87 (1839).
[3] *Mem. Geol. Surv. Gr. Brit.*, vol. i. p. 433 (1846).
[4] *The Connection of Geology with Terrestrial Magnetism*, ch. xiii. (1843).
[5] *Geological Observations in South America*, p. 168 (1846).
[6] *Excursions in Newfoundland*, vol. ii. p. 325 (1842).
[7] *Quart. Journ. Geol. Soc.*, vol. iii. p. 104 (1847). *Ibid.* vol. v. p. 129 (1849).
[8] *Edinb. New Phil. Journ.*, vol. lv. p. 137 (1853). *Phil. Mag.*, 4th ser., vol. xi. p. 20, and vol. xii. p. 127 (1856).
[9] *Phil. Mag.*, 4th ser., vol. xii. p. 37 (1856).

The exponents of such theories agree in referring the structure to the action of powerful lateral pressure, and in considering that such pressure operated simply by producing a distortion of the rock-mass upon which it was exerted. They differ to some extent, according to the special examples studied by each observer, as regards the precise kind of distortion produced, and the manner in which it has affected the intimate structure of the rocks in question.

We consider first, then, the kind of distortion which the rock, regarded for the present as a homogeneous mass, is supposed to have experienced under the action of the lateral pressure. If we imagine a sphere traced in the rock previous to its distortion, the effect of any uniform strain upon the mass will be to distort this sphere into an ellipsoid. This latter surface, which may be called the *strain ellipsoid*,[1] or ellipsoid of distortion, may conveniently be taken to express by its form and position the kind of strain or distortion undergone by the rock. We shall call its principal semiaxes, in descending order of magnitude, a, b, c. If the radius of the original sphere be k, it is evident that, in general, the distortion is accompanied by a change of volume in the ratio $abc : k^3$.

Mr. D. Sharpe's[2] conclusions were drawn from an examination of the fossils in the cleaved rocks of Tintagel and South Petherwin, but he extended them to all rocks having slaty cleavage, and confirmed them by the slates of North Wales, Westmoreland, and Cumberland. He says: 'It may be asserted as probable that all rocks affected by that peculiar fissile character which we usually call slaty cleavage, have undergone

'1. A compression of their mass in a direction everywhere perpendicular to the plane of cleavage.

'2. An expansion of their mass along the planes of cleavage in the direction of a line at right angles to the line of incidence of the planes of bedding and cleavage; or, in other words, in the direction of the dip of the cleavage.[3] No proof has been found that the rock has suffered any change in the direction of the strike of the cleavage planes. We must therefore presume that the masses of rock have not been altered in that direction.'

Assuming these laws, the strain ellipsoid would have its least axis perpendicular to the cleavage-planes, its greatest axis along the cleavage dip, and its mean axis along the cleavage-strike. Also the last clause in Mr. Sharpe's results makes $b = k$, and therefore the change of volume would be represented by the ratio $ac : b^2$. Mr. Sharpe speaks of the compression being 'compensated' by the expansion; if this is to be interpreted strictly, we should have $ac = b^2$, and no change of volume; but it is highly probable that in most cleaved rocks, ac would be less than b^2, and the volume would be reduced in proportion.

Dr. H. Clifton Sorby[4] examined the slates of Penrhyn and Llanberis, and the cleaved limestones and dolomites of Devonshire, and drew con-

[1] Thomson and Tait, *Natural Philosophy*, vol. i. pt. i. § 160, new ed. (1879). Minchin, *Treatise on Statics*, § 280, new ed. (1880).

[2] 'On Slaty Cleavage,' *Quart. Journ. Geol. Soc.*, vol. iii. p. 87 (1847).

[3] The latter form of statement must be preferred; the two expressions are clearly not equivalent, unless the strikes of the cleavage and the bedding coincide.

[4] 'On the Origin of Slaty Cleavage,' *Edinb. New Phil. Journ.*, vol. lv. p. 137 (1853). 'On Slaty Cleavage as Exhibited in the Devonian Limestones of Devon,' *Phil. Mag.*, 4th ser., vol. xi. p. 20 (1856).

clusions entirely in agreement with those of the geologist just quoted. It appears from his observations that a common form for the strain ellipsoid in the slates of North Wales is one whose axes are in such ratios as 1·6 : 1 : 0·27. These figures indicate a total diminution of volume in the ratio 0·43 : 1.

Professor S. Haughton [1] made numerical calculations of the distortion of form exhibited by the fossils of cleaved rocks, examining specimens from eight localities in Ireland, Cornwall, and Wales. He found a very marked compression in the direction perpendicular to the cleavage-planes, but his results led him to reject Mr. Sharpe's other laws relating to the expansion along the cleavage-dip and the unchanged dimensions along the cleavage-strike. His ellipsoid of strain was thus an oblate spheroid or ellipsoid of revolution, having its equator in the cleavage-plane. This implies, either no expansion in any direction, or equal expansion in all directions along the cleavage-planes. In the former case the diminution of volume would be in the ratio $c : b$ (or $c : a$); in the latter the diminution of volume, if any, would be indeterminate by this method. Professor Haughton's results, expressed in the notation already employed, are given in the following table:—

		Ratios of axes of ellipsoid
1	Carboniferous slate of Ardroginna, Waterford . .	0·975 : 1·000 : 0·412
2	" " South Petherwin, Cornwall .	1·010 : 1·000 : 0·256
3	" " Tintagel, Cornwall . .	0·669 : 1·000 : 0·102
4	Lingula beds of Abereiddy Bay, Pembrokeshire .	1·000 : 1·000 : 0·145
5	Green grits of Llyn Padarn, Llanberis . . .	0·805 : 1·000 : 0·531
6	Silurian black slates of Moel Benddu, North Wales .	1·000 : 1·000 : 0·270
7	" " Garth, Portmadoc . .	1·000 : 1·000 : 0·090
8	Carboniferous slate of Carrigaline, Co. Cork . .	1·000 : 1·000 : 0·466

In the last three examples it is *assumed* that a and b are equal, and c is calculated on this assumption, which seems scarcely warranted by the results obtained for the first five rocks examined. It will be noticed that Professor Haughton's investigations included the fossils on which Mr. Sharpe based his conclusions, but the more perfectly cleaved roofing slates, such as those of North Wales, studied by Dr. Sorby, are excluded, owing to the absence of fossils in them.

Professor J. Phillips,[2] in an early paper read before the British Association, described the distortion of cleaved rocks as a 'creeping movement among the particles of the rock, along the plane of cleavage, the effect of which was to roll them forward, in a direction always uniform over the same tract of country.' This rather indefinite language may be interpreted to mean what would now be termed a shearing motion [3] along the cleavage planes. In other words, if we conceive the rock divided into indefinitely thin slices, parallel to the cleavage planes, then each slice is supposed to have slipped an indefinitely small distance over its neighbour in the direction of the cleavage dip; the relative dis-

[1] 'On Slaty Cleavage and the Distortion of Fossils,' *Phil. Mag.*, vol. xii. p. 409 (1856). 'On a Model Illustrative of Slaty Cleavage,' *Brit. Assoc. Rep.*, 1857, Trans. sect. p. 69.

[2] 'On Certain Movements in the Parts of Stratified Rocks,' *Brit. Assoc. Rep.*, 1843, Trans. sects. p. 61.

[3] Thomson and Tait, *Natural Philosophy*, vol. i. pt. i. §§ 169–171, new ed. (1879). Minchin, *Treatise on Statics*, p. 474, new ed. (1880), Oxford.

placement of any two distant slices being proportional to the distance between them, and equal to s times that distance, where s is called the measure of the shear. A square (ABCD, fig. 1) would be distorted by the shear into a parallelogram (ABCD, fig. 2); and the ratio BE : AE would be the measure of the shear. The axes of the ellipsoid of strain would be in the ratios

$$\frac{\sqrt{s^2+4}+s}{2} : 1 : \frac{\sqrt{s^2+4}-s}{2}.$$

One set of circular sections of the ellipsoid would coincide with the cleavage planes, and its major axis would make with these planes the angle whose tangent is $\frac{b}{a}$. The axes would be such that $ac = b^2$, and there would be no change of volume in the rock during distortion.

FIG. 1.

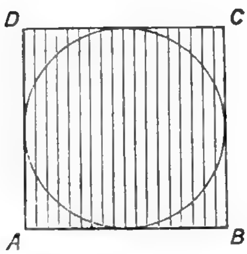
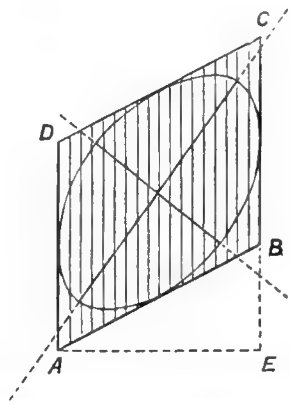


FIG. 2.



M. Aug. Laugel[1] also regarded cleavage planes as planes along which a shear (*glissement*) of the rock has taken place. It is easily seen, however, that such an idea is entirely incompatible with the observed facts. For the kind of distortion described implies (i.) no compression of the rock in a direction perpendicular to the cleavage planes, and (ii.) no distortion of plane objects lying in planes parallel to the cleavage planes. Moreover, as will appear in the next section, any mechanical theory of true slaty cleavage requires that the cleavage planes should be perpendicular to the least axis of the ellipsoid of strain.

Accordingly the Rev. O. Fisher, who formerly endorsed the theory just mentioned,[2] was led to change his opinion, and, while still describing the distortion of slate-rocks as a shear, to suppose that the shearing has taken place, not along the cleavage planes, but in such a direction that these planes are perpendicular to the least axis of the resulting strain ellipsoid.[3] But if there be, as seems to be indicated by the facts of cleavage, a diminution of volume during the process, the distortion of the rock cannot be resolved into shearing; and if, on the other hand, as Mr. Fisher maintains, there be little or no change of volume, it still seems simpler, as I have contended,[4] to describe the movement as a compression

[1] 'Du clivage des roches,' *Bull. de la Soc. Géol. de Fr.*, 2e sér., t. xii. p. 363 (1855).
[2] 'On Faulting, Jointing and Cleavage,' *Geol. Mag.*, 1884, p. 268.
[3] 'On Cleavage and Distortion,' *Geol. Mag.*, 1884, p. 396.
[4] 'On the Cause of Slaty Cleavage,' *Geol. Mag.*, 1885, p. 15; Reply, *Ibid.* p. 174.

perpendicular to the cleavage-planes accompanied by a *compensating* expansion along the cleavage-dip, for to this his shearing, with the necessary rotation concurrent with it, may be reduced. In this case the strain ellipsoid, having b a mean proportional between a and c, differs both from that of Dr. Sorby, in which b is greater than that mean proportional, and from that of Professor Haughton, in which $a = b$.

Finally, it seems reasonable to suppose that the precise kind of distortion produced in a rock by powerful lateral pressure depends on the nature of the rock itself and on the intensity and duration of the pressure. We may perhaps distinguish, as I have elsewhere suggested,[1] three stages of the process, at any one of which it may be arrested. In the first stage the rock-mass yields by a simple lateral compression with no considerable expansion to compensate it; the volume is accordingly diminished, this being effected by the closer packing of the constituent fragments and the expulsion of the greater part of the interstitial water. In the second stage the limit of this packing has been reached, and further lateral compression is therefore compensated by expansion along the cleavage-dip, there being no diminution of volume. In the third stage the intense pressure facilitates chemical changes in the rock, involving a further diminution of bulk, and so a lateral compression only partially compensated by expansion along the cleavage-dip. The strain ellipsoid of Professor Haughton would characterise the first stage, that of Dr. Sorby the latter stages of the process.

A rock may, of course, be operated upon, either successively or simultaneously, by pressures in two or more directions, and the cleavage-structure will be determined by the resulting distortion. For instance, there may be compressions in two directions and an expansion in the direction perpendicular to both, producing a very prolate strain ellipsoid, in which b and c are nearly equal and a considerably greater. In this case the rock would have the fibrous structure which Professor A. Heim[2] denominates *linear* cleavage as distinguished from ordinary plane cleavage, and which has been artificially imitated in the well-known experiments of MM. Tresca[3] and Daubrée.[4] Instead of a plane of cleavage there is an axis of cleavage.

III. *The Mechanical Theory of Slaty Cleavage: the Intimate Structure of Cleaved Rocks.*

The direct evidence for the distortion of cleaved rocks and the methods of arriving at a numerical estimate of it will be treated in the next section. At present we have to consider what effect such distortion has upon the intimate structure of these rocks, and how slaty cleavage is only a logical consequence of it.

Mr. Sharpe,[5] examining certain coarse brecciated bands in the slate quarries of Langdale and Patterdale, noticed that the included large fragments, of which the rock was to a great extent made up, were compressed perpendicularly to the cleavage-planes and elongated along the cleavage-dip, thus approximating, when allowance was made for their

[1] 'On the Successive Stages of Slaty Cleavage,' *Geol. Mag.*, 1885, p. 266.

[2] *Mechanismus der Gebirgsbildung*, Bd. ii. s. 59 (1878), Basel. See also Dufet, *Ann. de l'Ecole Norm. Supér.*, sér. 2, t. iv. p. 184 (1875).

[3] *Sur l'écoulement des solides*, 1872, Paris.

[4] *Etudes Synthétiques de Géologie Expérimentale*, 1879.

[5] *Quart. Journ. Geol. Soc.*, vol. v. p. 112 (1849).

irregular shapes, to an almond-like or ellipsoidal form. Observing with a glass the fine-grained slates, he was of opinion that they too presented the same structure on a small scale, their minute constituent fragments tending to the general form of ellipsoids with their shortest axes perpendicular to the cleavage-planes and their longest axes along the cleavage-dip. He pointed out that a rock having this constitution would, in consequence, split most readily in a direction perpendicular to the shortest axes of the ellipsoids, and so to the greatest compression of the rock-mass, for such a surface of fracture would run along the flattest faces of the fragments and meet the smallest number of them. The cleavage perpendicular to the direction of greatest compression in the rock was thus accounted for. Mr. Sharpe also maintained that there would be a second, though less perfect, cleavage perpendicular to the strike of the first, and so parallel to what the workmen call the 'side' of the slate; but we shall see that this could not be called a direction of cleavage in the strict sense of the word.

The author quoted considered, then, that the distortion of the rock-mass was shared by the ultimate fragments composing it. Dr. Sorby, on the other hand, held that the yielding of the rock was effected by a sliding of the originally flat or linear fragments over one another and a re-arrangement of them approximately perpendicular to the greatest compression of the rock. He supposed that the rocks which now form slates were originally composed, to a large extent, of flat and linear elements: in the slates of Penrhyn, of Llanberis,[1] about half the bulk of the rock consists of minute flakes of mica averaging $\frac{1}{1000}$ inch in length and $\frac{1}{10000}$ inch in thickness; in the Devonian limestones of Devonshire[2] fragments of crinoids and corals play a similar part. In certain uncleaved rocks of like composition the fragments lie in all directions at random, and we may suppose that the slate-rocks and limestones in question had originally a similar constitution. When the rock experienced a lateral compression and an expansion in a direction perpendicular to it, the fragments moved with the mass; there was thus a tendency in the flat constituents to set themselves perpendicular to the direction of the greatest compression, and in the linear fragments to arrange themselves not only approximately perpendicular to the compression, but also roughly parallel to the direction of expansion. In this way a structure would be set up in the rock effectively the same as that supposed by Mr. Sharpe, but arising in a different way. Premising that the two theories are by no means mutually exclusive, we may go on to consider that of Dr. Sorby more closely.

Conceive a number of planes traced in the rock, having the same 'strike' as the cleavage, and arranged, previously to the distortion, at equal angular intervals: fig. 3 shows the traces of such planes on a plane perpendicular to the cleavage-strike. After the distortion of the whole it is clear that all the planes will have been turned so as to make smaller angles with the plane perpendicular to the greatest compression, or, in other words, the principal diametral plane of the strain-ellipsoid; and, further, the planes in the neighbourhood of that plane will be more closely packed together than those more remote (fig. 4). In fact, if θ be the angle made before distortion by any one of these planes with the plane

[1] *Edinb. New Phil. Journ.*, vol. lv. p. 137 (1853). *Phil. Mag.*, 4th ser., vol. xii. p. 127 (1856).

[2] *Phil. Mag.*, vol. xi. p. 20 (1856).

perpendicular to the greatest compression, the angle θ' which it makes after distortion will be given by the equation

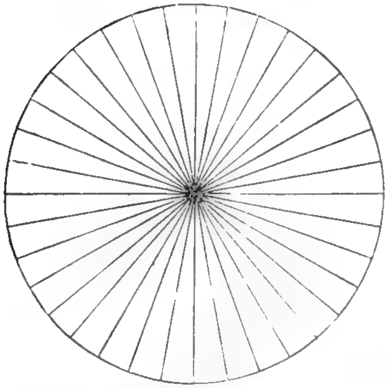
$$\tan \theta' = \frac{c}{a} \tan \theta\,;$$

and if the number of such planes be indefinitely great, the closeness of their arrangement, after distortion, in the neighbourhood of the plane considered will be proportional to

$$\frac{\cos^2\theta}{\cos^2\theta'} \times \frac{a}{c}$$

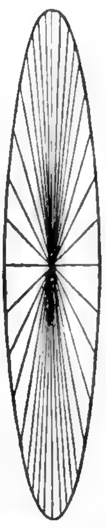
This expression becomes $\frac{a}{c}$ for $\theta'=0$, and $\frac{c}{a}$ for $\theta'=90°$; so the degree of closeness of the planes in the neighbourhood of the principal diametral plane of the strain ellipsoid is to that in the neighbourhood of the plane perpendicular to it in the ratio $a^2 : c^2$. Now let all these planes represent

FIG. 3.



Before compression and elongation.

FIG. 4.



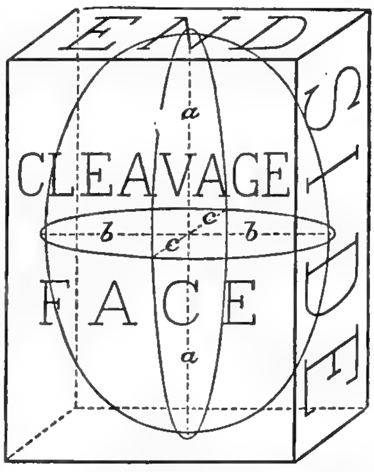
After compression and elongation.

flat fragments such as scales of mica originally arranged at random through the rock, and suppose the distortion such that $a = 6c$. Then after distortion the number of scales of mica making angles of less than 1°, say, with the principal diametral plane will be about 36 times the number making angles of less than 1° with the plane perpendicular to it; and it is easy to see that the rock must split with much greater readiness along the former plane than along the latter. The number 36, however, cannot be taken as giving any precise indication of the relative facilities of splitting in different directions, for, in the first place a slate-rock is not wholly made up of flat and linear particles, and secondly, the above mode of demonstration—that followed by Dr. Sorby and Professor Phillips—takes account only of those flat particles whose planes have their strike perpendicular to the direction of compression, or of linear particles whose long axes lie in vertical planes parallel to the direction of compression. A stricter investigation would be too tedious for insertion here. It is sufficient to notice that, according to the mechanical theory

here developed, of all planes passing through *b* (fig. 5), the facility of splitting is a maximum for that plane which also passes through *a*, and a minimum for that which passes through *c*. It is easy to see, from considerations precisely similar, that, of all planes passing through *c*, the facility of splitting is a maximum for that passing through *a* and a minimum for that passing through *b*: and, of all planes passing through *a*, the facility of splitting is a maximum for that passing through *b*, and a minimum for that passing through *c*. Summarising these conclusions, we may say that the plane through *a* and *b* gives a maximum, and that through *b* and *c* a minimum among all other planes in the rock, while the plane through *a* and *c* gives a maximum among all planes through *c*, and a minimum among all those through *a*. With respect to these results, two remarks may be made.

In the first place, the principal diametral plane of the strain ellipsoid which passes through *a* and *b* is the cleavage-plane *par excellence*; but the facility of cleavage along other planes nearly parallel to it is nearly as great, and it is evident that under suitable stresses the rock will split along any plane making a small angle with the true cleavage direction. This is not a truism, but a consequence of the fact that the facility of splitting along the true cleavage is a *maximum* in the proper mathematical sense, and varies continuously from that plane; the same would not be true of the crystalline cleavage of minerals.

Fig. 5.



The other point to be noticed is that, on this theory, there can be but one true cleavage direction: a plane parallel to the 'side,' *i.e.*, the plane passing through *a* and *c*, is not a cleavage-plane in the sense just indicated. For although the facility of cleavage along such a plane is a maximum for all planes passing through *c*, it is a minimum for all planes passing through *a*. A similar argument holds good on Mr. Sharpe's theory of the constitution of slate-rock, and his 'secondary cleavage' seems to be no more than the properties of 'side' referred to below, in Section VI. It has been suggested[1] that a second cleavage might arise from the action of a second and subsequent lateral pressure, operating in a different direction from the first one. But this is not the case, for after any combination of uniform compressions and expansions of the rock, the strain surface will still be an ellipsoid, and the line of argument indicated above will hold for this final or resultant strain ellipsoid.

In the case of the fibrous or 'linear' cleavage mentioned above, a phenomenon of only local occurrence, if we suppose $b = c$, the facility of cleavage along all planes passing through *a* will be the same, and greater than that along any other plane. In the case of Professor Haughton's strain ellipsoid, in which $a = b$, it will be seen that the facility of cleavage will be the same for all planes passing through *c*, which is incompatible with the distinctive properties of the 'side' and 'end,' recognised by the quarrymen in all the best roofing-slates.

[1] *Quart. Journ. Geol. Soc.*, vol. v. p. 116 (1849), &c.

I have not thought it necessary in the foregoing *résumé* to discuss all the views concerning cleavage propagated prior to the development of the mechanical theory, since they were, for the most part, founded on very meagre evidence as to the facts. Mr. W. Hopkins,[1] for instance, concluded from mathematical considerations, that, if the direction of the cleavage-planes in a rock be determined by stresses to which it has been subjected, those planes ought to be either perpendicular to the direction of maximum normal pressure, or parallel to the planes of maximum tangential stress, which make angles of 45° with the maximum normal pressure. From an examination of Mr. Sharpe's distorted fossils only, he was led to fix on the latter supposition, whereas the truth of the former, which was that embraced by Mr. Sharpe himself, has since been amply confirmed.

Neither have I noticed explicitly the objections brought against a mechanical explanation of slaty cleavage by Professors Sedgwick,[2] H. D. Rogers,[3] and others, for such objections are found to disappear on a fuller examination of both the theory and the facts, and are indeed implicitly answered by the more complete exhibition of that theory in its various applications.

IV. *The Mechanical Theory of Slaty Cleavage: the Direct Evidence of the Distortion of Cleaved Rocks.*

The most obvious information regarding the distortion which cleaved rocks have undergone is that derived from the contortions produced in intercalated beds of less yielding materials. A typical example in the cliffs near Ilfracombe was described and figured by Dr. Sorby,[4] and has been frequently copied.[5] Here a bed of coarse-grained sandy slate occurs among fine-grained shaley slate, and is seen to have been forced into a series of bold undulations, although the bedding at a short distance above and below is undisturbed. The axial planes of the undulations coincide with the cleavage-planes of the finer slate,[6] and the thickness of the sandy bed at the troughs and crests of the undulations is four times the thickness at the intermediate places. The clear interpretation of this section is that the whole has undergone a lateral compression of considerable amount, partly compensated by yielding in an upward direction perpendicular to the compression; and further, that the direction of compression, as deduced from the position of the axial planes of the folds, is at right angles to the cleavage-planes. Similar phenomena may be observed in almost any of the slate-quarries of North Wales.

Dr. Sorby also made use of the evidence of the greenish spots, apparently of concretionary origin, which are of common occurrence in the Welsh roofing-slates examined by him. These spots may be assumed

[1] 'On the Internal Pressure to which Rock Masses may be subjected, and its Possible Influence on the Production of the Laminated Structure,' *Trans. Camb. Phil. Soc.*, vol. viii. p. 456 (1847).

[2] *Synopsis of British Palæozoic Rocks*, Introduction (1855).

[3] 'On the Laws of Structure of the More Disturbed Zones of the Earth's Crust,' *Trans. Roy. Soc. Edinb.*, vol. xxi. p. 431 (1856).

[4] *Edinb. New Phil. Journ.*, vol. lv. p. 137 (1853).

[5] Tyndall, *Phil. Mag.*, 4th ser., vol. xii. p. 41 (1856). Phillips, *Brit. Assoc. Rep.*, 1856, p. 385. Lyell's *Student's Elements*, p. 594, 2nd ed. (1874). Forbes, *Pop. Sci. Rev.*, 1870, &c.

[6] Cf. fig. *Quart. Journ. Geol. Soc.*, vol. xxxv. p. 88 (1879), where unsymmetrical flexures are seen to follow the same law.

to have been originally spherical, or perhaps slightly extended in the direction of the stratification so as to form a rather oblate spheroid; but their present shape is that of an ellipsoid of three unequal axes, viz., the greatest axis in the plane of cleavage and along its dip; the mean axis in the plane of cleavage and along its strike; the least axis perpendicular to the plane of cleavage; thus indicating a compression perpendicular to the cleavage-planes, and an expansion along them in the direction of their dip. In fact, if the original form was spherical, the present form of these spots must give us the strain ellipsoid itself. If, however, as suggested by Mr. Fisher,[1] the formation of these spots be posterior to that of cleavage, we must account for their form by 'the chemical influence spreading most readily along the grain of the slate, and with greatest difficulty across its laminæ,' and in this case no quantitative conclusions can be drawn from the phenomena.

The most valuable evidence of the nature and amount of the distortion of cleaved rocks is that obtained by noting the altered forms of contained fossils. The merit of first applying numerical calculation to this line of inquiry belongs to Professor Haughton,[2] whose work has already been alluded to. We are, however, not justified in assuming that the deformation of the fossils is invariably a correct measure of the distortion of the rocks themselves. A hard substance imbedded in a softer matrix would evidently yield but slightly, or not at all, to any compression to which the mass as a whole might be subjected; and it is a matter of common observation that in many slate-rocks those fossils of more solid substance or stouter form are comparatively unchanged in shape, while those of slighter build exhibit a marked deformation. It might be possible by noting the degrees of distortion of different kinds of fossils in the same rock to form some idea of the consistency of that rock at the time of its deformation. Meanwhile, it may be remarked that the distortion of the rock as deduced from the forms of its contained fossils will be in all cases an under rather than an over-estimate; and where different kinds of fossils in the same rock exhibit deformation to the same extent, we may reasonably suppose that they have all shared to the full the distortion of the rock itself.

Taking this last case, it is clear that the degree of distortion of the fossils must be in direct relation with the form of the strain ellipsoid, so that with sufficient data the latter may be deduced from the former. It will be convenient to adopt the usual assumption that the bedding and cleavage have the same strike, and to regard the fossils as plane figures lying parallel to the bedding.

Fig. 6 is taken in a plane perpendicular to the common strike of bedding and cleavage. The ellipse is the section by this plane of the strain ellipsoid, AOA′, COC′, are the greatest and least axes of the ellipsoid; POP′ is the trace of the bedding-plane, and the angle AOP is the angle between the planes of bedding and cleavage, which we shall call ϕ. If the radius OP be called ρ, then

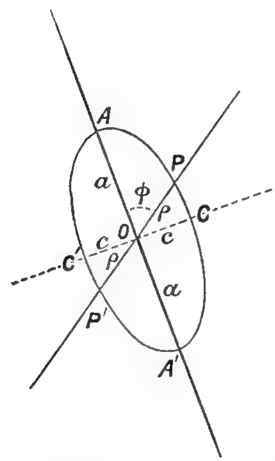
$$\frac{1}{\rho^2}=\frac{\cos^2\phi}{a^2}+\frac{\sin^2\phi}{c^2} \quad \text{(i.)}$$

The plane of bedding cuts the strain ellipsoid in an ellipse whose semi-axes are ρ and b, and this may be called the strain ellipse for objects

[1] *Geol. Mag.*, 1884, p. 402. [2] *Phil. Mag.*, 4th ser., vol. xii. p. 409 (1856).

lying in the plane of bedding, since its form expresses completely the distortion of such objects. If the radius of the original sphere before distortion be k, the dimensions of any fossil lying in the bedding-plane have been altered in the ratio $\rho : k$ along the dip, and in the ratio $b : k$ along the strike. If there be no alteration along the direction of the strike, $b = k$; but without making this assumption, we may say, in Professor Haughton's terminology,[1] that the *distortion* along the dip is $\frac{\rho}{b}$, or the distortion along the strike $\frac{b}{\rho}$.

FIG. 6.



It is of importance to notice that although the rock is supposed to undergo an expansion along the *cleavage*-dip, the distortion along the dip of the *bedding* may be either an expansion or a compression, according as the angle between the bedding and the cleavage is small or great; for it is easy to see from equation (i.) that ρ may be either greater or less than b. If the bedding-plane happen to make such an angle with the cleavage that $\rho = b$, its strain ellipse is a circle, and the fossils suffer no deformation in the bedding-plane. It follows from equation (i.) that in this case

$$\tan^2\phi = \frac{\frac{1}{b^2} - \frac{1}{a^2}}{\frac{1}{c^2} - \frac{1}{b^2}};$$

for smaller values of ϕ, ρ is greater than b, and the distortion of the fossils is a relative expansion along the dip of the bed; for greater values of ϕ, ρ is less than b, and the distortion is a compression along the dip. If, as Professor Haughton maintains, in the rocks examined by him, the strain ellipsoid be one of revolution, having $a = b$, the circular sections must be parallel to the cleavage. In this case there will be no deformation of fossils when the bedding and cleavage coincide, but in every other position of the bedding relatively to the cleavage there will be a compression of the fossils in the direction of the dip. These conditions do not appear to be always verified even in the localities studied by Professor Haughton.[2] Reverting, then, to the general case, it is manifest that the distortion along the dip is an expansion $\frac{a}{b}$ when the bedding and cleavage coincide, and a compression $\frac{c}{b}$ when they are at right angles. For any other position the distortion $\frac{\rho}{b}$ may be determined from the equation

$$\left(\frac{b}{\rho}\right)^2 = \left(\frac{b}{a}\right)^2 \cos^2\phi + \left(\frac{b}{c}\right)^2 \sin^2\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{ii.})$$

[1] *Loc. cit.* p. 410. There seems to be some obscurity here. The only two lines which are at right angles to one another, both before and after distortion, are those parallel to the dip and strike respectively.

[2] *E.g.*, in the Portmadoc district, both in the Lingula Flags of Borth and the Tremadoc beds of Garth Hill.

By observing the distortions $\frac{b}{\rho}$ and $\frac{b}{\rho'}$, for two places in the same locality where the bedding makes angles ϕ and ϕ', respectively, with the cleavage, we can calculate the ratios of the axes of the strain ellipsoid. For it is easy to show that, from equation (ii.) and the corresponding one, we obtain

$$\left(\frac{b}{a}\right)^2 = \frac{\left(\frac{b}{\rho'} \sin \phi + \frac{b}{\rho} \sin \phi'\right)\left(\frac{b}{\rho'} \sin \phi - \frac{b}{\rho} \sin \phi'\right)}{\sin (\phi + \phi') \sin (\phi - \phi')} \quad . \quad . \quad \text{(iii.)}$$

$$\left(\frac{b}{c}\right)^2 = \frac{\left(\frac{b}{\rho} \cos \phi' + \frac{b}{\rho'} \cos \phi\right)\left(\frac{b}{\rho} \cos \phi' - \frac{b}{\rho'} \cos \phi\right)}{\sin (\phi + \phi') \sin (\phi - \phi').} \quad . \quad . \quad \text{(iv.)}$$

The practical question is, then, how to determine the distortion $\frac{\rho}{b}$ for any position of the bedding-plane by observations of deformed fossils in that plane. Let us call the *length* of a fossil, such for instance as a trilobite, that line about which, in an undistorted specimen, there is bilateral symmetry, and let the *breadth* be measured along a line which before distortion is at right angles to the length. The length and breadth of a distorted fossil will not in general be at right angles to each other: they will be so only when one of them lies in the direction of dip, and consequently the other in the direction of strike. In this special case we may profitably adopt Professor Haughton's method, viz., comparing the relative dimensions of the distorted fossil with the known relative dimensions of the species when undistorted. If the length of the fossil lie in the direction of dip, the ratio of its length to its breadth, divided by the ratio of length to breadth in an undistorted specimen, will give $\frac{\rho}{b}$; if the breadth of the fossil lie in the direction of dip, the same calculation will give $\frac{b}{\rho}$. If on the same slab of rock occur specimens in the two positions, we can estimate the distortion without knowing the undistorted form of the species; for if we divide the ratio of length to breadth of a specimen in the former position by the ratio of length to breadth of a specimen in the latter, we get at once $\left(\frac{\rho}{b}\right)^2$.

A single specimen of a fossil whose length and breadth lie oblique to the dip and strike, is sufficient to determine the distortion without previous knowledge of the form of the species when undistorted. For if α and β be the angles which the length and breadth make with the direction of dip, it is readily proved that

$$\left(\frac{b}{\rho}\right)^2 = \tan \alpha \tan \beta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(v.)}$$

This method is readily applied, and if the length and breadth make considerable angles with the dip, it is very accurate. It is tantamount to that employed by M. H. Dufet,[1] who, however, makes use of geometrical constructions.

[1] 'Déformations des Fossiles, &c.,' *Ann. de l'Ecole Norm. Sup.*, sér. 2, t. iv. p. 183 (1875).

We have already remarked that the extent to which the fossils partake of the distortion of their matrix depends necessarily on the relative consistencies of the two at the time of the distortion. It should be added, for the sake of completeness, that sometimes hard but brittle fossils, such as the guards of belemnites, have been able to resist distortion, but have yielded by fracture. In such cases the several portions of the fossil are found to be separated from one another in the direction of the cleavage dip; and we have in these rocks, not only a proof, but a direct measure (which cannot be an over-estimate) of the expansion of the rock in that direction. Examples are quoted by MM. Heim [1] and Daubrée; [2] and we may see that at the time of the distortion the rocks must have already acquired a degree of firmness and hardness, from the fact that the separation of the fragments of the fossils left cavities, which were only subsequently filled by crystallised calcite.

V. *Slaty Cleavage in Rocks of various Lithological Characters.*

Slaty cleavage is by no means confined to the rocks of any one geological period or era, but owing to its association with earth-movements on an extensive scale, the structure is, in the British Isles, characteristic of the older Palæozoic formations. The best slates of North Wales are procured from the Lower Cambrian strata, as at Penrhyn, Llanberis, and Nantlle, and from the Bala and Llandeilo beds, as at Ffestiniog and other places. The slates of the Lake District also are referred to the Bala and Arenig series, but slates of Devonian age are worked in Cornwall, and Carboniferous in Devonshire. In different parts of Europe, North America, &c., good slates are obtained from strata of Jurassic, Cretaceous, and Tertiary ages.

But although the structure is not restricted to strata of any special geological age, its association with rocks of particular lithological types has been noted from an early date. It is met with in perfection in argillaceous rocks of fine texture and in fine-grained fragmental rocks of volcanic origin. A specimen in the Woodwardian Museum shows fifty slates split from a block $3\frac{1}{2}$ inches in thickness, and in the Nantlle quarries, where this was obtained, the best slates are usually from $\frac{1}{8}$ to $\frac{1}{10}$ inch thick. The Llanberis slates are similar, and the beds at Ffestiniog are even more yielding. The degree of thinness to which the slates can be split in working depends, however, not only on the perfection of the cleavage structure, but also on the flexibility and toughness of the rock.

Some argillaceous limestones exhibit cleavage well developed, as do others, for example some in Devonshire, which are almost purely calcareous and dolomitic. In some cases a relation is observable between the percentage of argillaceous matter and the facility of cleavage. An excellent instance is furnished by a section in the Lias at Grenoble, where several beds of argillaceous limestones of different compositions are exposed, and those with the greatest amount of argillaceous matter are found to present the best cleavage. M. E. Jannettaz [3] has examined these different strata by a method which he has applied with success to

[1] *Mechanismus der Gebirgsbildung*, Atlas, Taf. xiv., figs. 1–5 (1883).
[2] *Etudes Synthétiques de Géologie Expérimentale*, p. 404 (1879).
[3] 'Mém. sur les Clivages des Roches, &c.,' *Bull. de la Soc. Géol. de France*, sér. 3, t. xii. p. 216 (1884).

other non-isotropic rocks and minerals; a method depending on the fact, that a cleaved rock conducts heat better along than across the cleavage-planes. His process is to cut a section perpendicular to the cleavage, coat the surface with a thin film of grease, and heat at one point. It is found that the curve marked out by the ridge of melted grease after its cooling is not a circle, but an ellipse whose longer axis is along the trace of the cleavage. The ratio of the axes of this ellipse indicates the relative thermal conductivity of the rock along and across the cleavage-planes, and may be regarded as, to some extent, an index of the non-isotropic character of the rock.[1] In the Grenoble section this ratio was found to be greatest in those beds which contained most argillaceous and least calcareous matter, as appears from the table quoted below.

Percentage composition		Ratio of axes of ellipse of conductivity
Argillaceous matter	Calcareous matter	
62	38	1·04
35	65	1·23
6	94	1·1
10	90	1·06

Sandstones, for the most part, are capable of taking but a very rude cleavage. In Wales the diabase dykes, so common in some slate-quarries, occasionally exhibit the same structure in a very imperfect degree.

When alternating beds of different lithological characters have been subjected alike to the forces which produce cleavage, it frequently happens, as was long ago noticed,[2] that the more fine-grained and argillaceous beds have acquired a cleavage-structure, while the coarser beds, calcareous or arenaceous, have not been so affected. Even when intercalated sandy beds among slate rocks have received a certain cleavage structure, it is not only of a more rudimentary character than that of the slate-rock, but has a slightly different angle of dip, the cleavage surfaces being bent or curved at the junction of the two kinds of rocks. Most writers on the subject of cleavage have described instances of these phenomena. In the Welsh slate quarries the 'steps' produced in the cleavage planes by the thin gritty bands of rock are very noticeable. Where the slate rock rests upon a gritty band, the dip of the cleavage is seen to change abruptly on passing from the one rock to the other, the deviation sometimes amounting to as much as 20° or 30° (fig. 7). On emerging into the slate rock again, the cleavage planes resume their original direction in a manner suggestive of the refraction of a ray of light through a plate of glass. If gritty bands of different textures occur

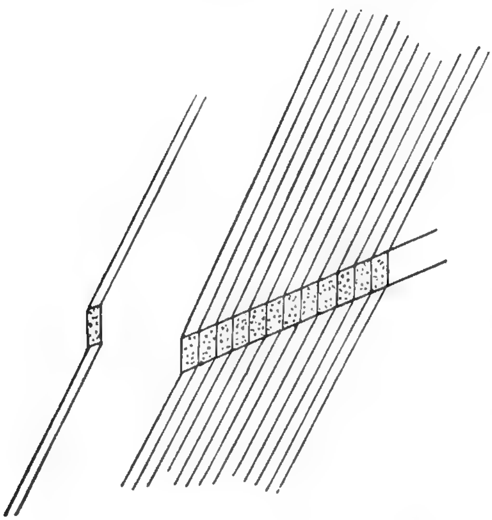
[1] This ellipse is not, however, the same as the trace of the strain ellipsoid; its axes are in the same directions as those of the latter, but less unequal. For example, in some slates from Nantlle and Groeslon, I find for the ratio of the axes of the ellipse of conductivity, by three experiments, the numbers 1·23, 1·24, 1·21; the ratio of the axes of the strain ellipse is much greater. Cf. Dufet, *Ann. de l'Ecole Norm. Sup.*, sér. 2, t. iv. p. 185 *et seq.* (1875).

M. Jannettaz has also shown that the conductivity in the direction of cleavage-dip is slightly greater than that in the direction of cleavage-strike, which is in accordance with what might be expected.

[2] *E.g.*, De la Beche, *Geological Observer*, p. 616, 2nd ed. (1853). Geikie's *Textbook of Geology*, p. 311, figs. 75, 76 (1882).

together, there may be two or more successive 'refractions' of small amount (fig. 8), and if the texture of the foreign bed change gradually upward, so as to pass into the overlying slate rock, the cleavage surfaces assume a curved form as in fig. 9.

FIG. 7.



The following rules seem to hold good in all such deviations of the cleavage surfaces :—

(i.) In passing from slate rock to a gritty band, or from a finer gritty band to a coarser, the cleavage planes are invariably bent so as to make a higher angle with the bedding.

(ii.) The deviation of the cleavage planes is of greatest amount, *ceteris paribus*, when they cut the bedding at a moderate angle. If perpendicular, there is no deviation, and if the angle be very small, the cleavage produced in the gritty band is of a very rudimentary character, the band,

FIG. 8.

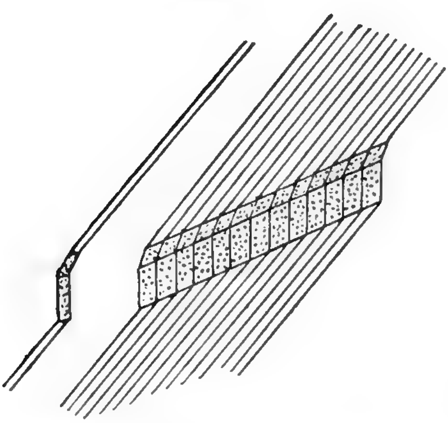
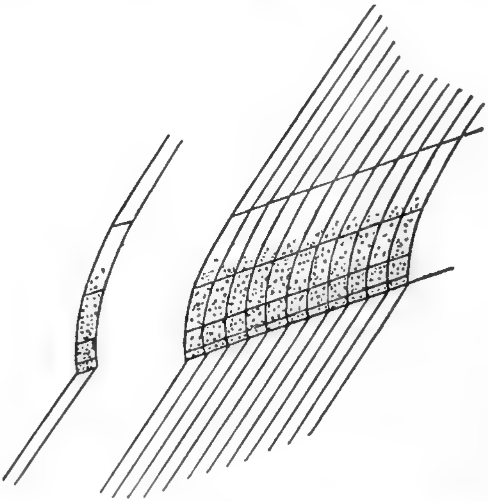


FIG. 9.



if thin, splitting in an irregular manner mainly in the direction of the bedding.[1]

[1] Professor Hughes has observed that in cleaved flagstones, 'when the cleavage-planes approach within about 15° of the stratification, the rock is apt to split along the lines of bedding.' [Lyell's *Student's Elements*, 3rd ed., p. 590 (1878).] In the Lingula flags of the Nantlle valley and of the Portmadoc district, it is easy to find wedge-shaped 'junction-specimens' of slate and flags, having opposite faces slightly inclined, one being a cleavage-plane of the slate, and the other a bedding-plane of the flags.

Good slate-rock will split truly along the cleavage-planes, however near these may be to the bedding.

Dr. Sorby[1] long ago noted similar laws, and gave his explanation of the phenomenon, which is briefly this. Since the grit yields less than the slate to the compressing force, the total voluminal compression is greater for the slate than for the grit. But near the junction of the two rocks the change of dimensions in the direction parallel to the bedding must be the same for both. Consequently, in the direction perpendicular to the bedding, the slate undergoes a less expansion (or greater compression) than the grit; and the cleavage planes, which are in each rock perpendicular to the direction of greatest compression, will therefore be less inclined to the bedding in the slate than they are in the grit.

Professor Tyndall[2] draws quite different conclusions from the phenomena in question, connecting the deflection of the cleavage planes with the progressive development of the structure concurrently with the contortion of the beds. Referring to a contorted gritty bed intercalated in slate-rock, he says: 'When the forces commenced to act, this intermediate bed, which, though comparatively unyielding, is not entirely so, suffered longitudinal pressure; as it bent, the pressure became gradually more lateral, and the direction of its cleavage is exactly such as you would infer from a force of this kind; it is neither quite across the bed, nor yet in the same direction as the cleavage of the slate above and below it, but intermediate between both.'

The latter statement seems rather obscure, and raises the question how far the production of the cleavage structure and the concomitant contortion of the strata can be regarded as contemporaneous. Dr. Sorby's exposition seems sufficient, and is a necessary consequence of the mechanical theory. To compare the theory with the phenomena we may proceed as follows.

Let a, b, c be the semiaxes of the strain ellipsoid for the slate, and a', b', c' for the grit, and let ϕ and ϕ' be the angles between the bedding and cleavage for the two rocks respectively. Referred to axes respectively parallel and perpendicular to the bedding, the Cartesian equation to the ellipse in fig. 6 is, for the slate,

$$\frac{(x\cos\phi + y\sin\phi)^2}{a^2} + \frac{(y\cos\phi - x\sin\phi)^2}{c^2} = 1 \quad . \quad . \quad . \quad . \quad . \quad \text{(vi.)}$$

The change of volume is in the ratio $\frac{ac}{b^2}$ for the slate, and $\frac{a'c'}{b^2}$ for the grit, and, consequently, if we call the ratio $ac : a'c'$, m, the equation to the ellipse for the grit is

$$\frac{(x\cos\phi + my\sin\phi)^2}{a^2} + \frac{(my\cos\phi - x\sin\phi)^2}{c^2} = 1 \quad . \quad . \quad . \quad . \quad \text{(vii.)}$$

By the usual rule for finding the axes of an ellipse, we may deduce that

$$\cot 2\phi' = \frac{\cot\phi\,(m^2a^2 - c^2) - \tan\phi\,(a^2 - m^2c^2)}{2m\,(a^2 - c^2)} \quad . \quad . \quad . \quad . \quad . \quad \text{(viii.)}$$

From this last equation it may be seen that if $\phi = 0$, $\phi' = 0$; and if $\phi = 90°$, $\phi' = 90°$; but in any other case ϕ' is less than ϕ (for m is, of

[1] *Edinb. New Phil. Journ.*, *cit.* (1853). Cf. Professor H. D. Rogers, *Trans. Roy. Soc. Edinb.*, vol. xxi. p. 449 (1856).

[2] *Phil. Mag.*, 4th ser., vol. xii. p. 43 (1856).

course, less than unity). This is in accordance with the rules stated above, as deduced from observation. To obtain a numerical test, suppose that, during the process which results in the cleavage structure, the slate is reduced to half its former volume, while the grit remains unchanged in bulk, so that $m=\frac{1}{2}$. Suppose, too, that the distortion of the slate is such that $a=6c$; then equation (viii.) becomes

$$\cot 2\phi' = \frac{8}{35}\cot\phi - \frac{143}{140}\tan\phi; \quad \ldots \ldots \quad \text{(ix.)}$$

from which we can find ϕ' when ϕ is known. Thus, if $\phi=45°$, we get $\phi'=64° \ 12'$, and therefore the deflection of the cleavage planes would be $19° \ 12'$; or if $\phi=30°$, we get $\phi'=46° \ 45'$, and so a deflection of $16° \ 45'$. These figures agree very well with observation.

As an approximate rule, when the slate is strongly cleaved, we may use the equation

$$\tan\phi' = \tan\phi \div m, \quad \ldots \ldots \quad \text{(x.)}$$

which results from neglecting the quantity $\frac{c^2}{a^2}$ in equation (viii.).

Another peculiarity of contorted gritty bands intercalated among slate rocks may be investigated by means of the above considerations—viz. the fact that a thin band of this kind is found to be thickened at the crests and troughs of the undulations (where the band is cut perpendicularly by the cleavage), and more attenuated at the intermediate places. In order to find a' and c' from equation (vii.), we may make use of the relation

$$\frac{1}{a'^2}+\frac{1}{c'^2}=\frac{\cos^2\phi+m^2\sin^2\phi}{a^2}+\frac{\sin^2\phi+m^2\cos^2\phi}{c^2},$$

which reduces to

$$a'^2+c'^2=\frac{1}{2m^2}\left\{(1+m^2)(a^2+c^2)-(1-m^2)(a^2-c^2)\cos 2\phi\right\}. \quad \text{(xi.)}$$

This equation, together with the one

$$a'c'=\frac{ac}{m}, \quad \ldots \ldots \quad \text{(xii.)}$$

suffices to determine a' and c'; and since the values thus obtained depend upon ϕ, the distortion of the gritty band will vary in different parts. It is greatest, as appears from equations (xi.) and (xii.), where $\cos 2\phi$ is least—*i.e.* where $\phi=90°$, or at the crests and troughs of the folds. At these places the thickness of the band is increased in the ratio $\sqrt{\left(\frac{2a}{c}\right)}$, which, with the numerical data assumed above, is 3·46. These numerical results accord very closely with what I have noted in the slate districts of North Wales.

Other peculiarities at the junction of slate-rock with a more gritty bed may be explained in a similar manner. One of these characters was mentioned and figured by Dr. Sorby in the Ilfracombe section already mentioned. On approaching the gritty band, which shows a series of contortions, the cleavage-planes of the slate are seen to curve slightly away from the crests of the folds, in a manner suggestive of 'stream-

lines' meeting an obstacle, and in fact for a similar reason. Very perfect examples of this peculiarity are sometimes seen in North Wales, *e.g.*, near the Dorothea Quarry, Nantlle.

Again, we may occasionally observe that where slate with a cleavage oblique to its bedding adjoins a harder bed or even such obstacle as a sheet of quartz along a joint-fissure,[1] the cleavage of the slate is slightly turned aside on approaching the harder bed, so as to make a smaller angle with it. Here a similar explanation may hold, as has been remarked by Mr. Sharpe. M. Laugel,[2] however, ascribed this phenomenon to a certain amount of shearing (*glissement*) along the planes of bedding, subsequently to the setting up of the cleavage structure; and there seem to be some cases of irregularity in cleavage-surfaces to which this explanation applies, as suggested by Professor T. McKenny Hughes.[3] There may even be a bending or crumpling of the cleavage-surfaces where they meet planes which are not those of bedding,[4] for it is obvious that those surfaces must share all subsequent vicissitudes of the rocks in which they occur. In the cases figured by Sir H. De la Beche[5] it is possible, as he suggested, that the beds have shrunk owing to the abstraction of some constituent by solution.

VI. *The Mode of Working Slate-Rock in the Quarries.*

The behaviour of slate-rock when broken and split agrees perfectly with its intimate structure as described in the foregoing pages. Besides the cleavage, the Welsh quarrymen[6] recognise in slate a certain 'grain' giving the rock different properties along different directions in the cleavage-plane. The facts are completely in accord with the deductions made above as the results of the mechanical theory. A slate breaks across the cleavage more readily parallel to its 'length' or 'side,' *i.e.*, the cleavage-dip, than it does parallel to its 'breadth' or 'end,' *i.e.*, the cleavage-strike. In a case where it is difficult to ascertain by merely looking at a block which is its length and which its breadth, the quarryman tries to find a chip on its surface: on striking this with a hammer it is found to break (*stolpio*) parallel to the length or side of the block.

In breaking across the massive blocks or slabs of rock which are afterwards to be split into roofing-slates, the same peculiarity of structure shows itself. If a block is to be broken lengthwise, it is sufficient to cut a slight groove at one end, place the edge of a chisel on it, and strike a blow with a hammer. The cut travels tolerably straight along the length of the block, although its surface often becomes grooved and fluted towards the further end. The object of the groove is to steady the chisel for the first blow, and in cutting smaller blocks it may be dis-

[1] Sharpe, *Quart. Journ. Geol. Soc.*, vol. v. p. 117 (1849). Forbes, *ibid.*, vol. xi. p. 170 (1855).

[2] *Bull. Soc. Géol. Fran.*, sér. 2, t. xii. p. 363 (1855).

[3] Lyell's *Student's Elements of Geology*, p. 590, 3rd ed. (1878).

[4] Jukes, *Quart. Journ. Geol. Soc.*, vol. xxii. p. 359 (1866).

[5] *Geological Observer*, p. 709 (1851). Geikie's *Textbook of Geology*, fig. 248, p. 522 (1882).

[6] The following remarks apply more particularly to the Lower Cambrian slates of North Wales. I am greatly indebted to C. W. Rathbone, Esq., Manager of the Pen-y-bryn Quarry at Nantlle, who has afforded me every opportunity of examining the working of the slate-rock, and to Messrs. J. T. Parry and John Roberts, of the same quarry, who have kindly given me the benefit of their large practical experience.

pensed with. For cutting across a block in a direction parallel to the 'end,' a circular saw worked by steam is employed in the larger quarries, and when the operation is performed by hand it requires much more care than cutting in the other direction. The method employed is to cut and carefully smooth a groove in one 'side' of the block, then turn it over and strike a heavy blow with a mallet upon the opposite point of the other 'side.' If the 'side' is smooth and perpendicular to the cleavage-face, a cut may be started with a chisel instead of the groove, but for a block whose 'sides' are 'bevel' the method described above must be adopted.

Again, in splitting the blocks into slates, the split is always effected from 'end' to 'end,' because it is thus less liable to 'run out' across the cleavage than if the operation were attempted from the 'side.' There are, however, in some parts of North Wales certain 'veins' or beds of slate which can be cleaved from the 'side.' In this case, too, the blocks can be cut across by the same process as that described for cutting them lengthwise. Such 'veins' are said by the quarrymen to have 'no length and breadth,' and we may suppose that in them the strain ellipsoid is one of rotation, as in Professor Haughton's calculations. Certain beds of slate which are rather coarse-grained at the bottom and grow finer upwards, must be split always from the *top* 'end'; such is the case in some of the Ffestiniog veins.

The fine striæ seen on the surface of a slate, and regarded by Mr. Fisher[1] as an arrangement analogous to 'craig and tail,' connected with the shearing movement of the rock-mass, seem, however, to be dependent less on the 'grain' than on the method of splitting the rock into slates. When a block has been roughly split off by a blow upon a chisel applied at the end, it is seen that the striæ are not straight and parallel, but diverge in curves from the point of percussion, and sometimes from harder lumps or bands in the slate. This appearance is not observable in a slate split in the ordinary way, for the cleavage is opened by two broad chisels inserted at the end, and the resulting surface shows therefore a system of roughly straight and parallel striæ, as may be well seen on wetting a cleavage-face of an ordinary roofing-slate.

The mode of splitting a block into slates also illustrates the internal structure of the rock. A block is taken of sufficient thickness to yield say eight slates; this is split into two 'fours,' each of these into two 'twos,' and finally each of the latter into two slates. In this last stage of the process there is a tendency for the split to 'run out' to the face of the slate on the weaker side. Accordingly, after starting the split at one 'end' by two broad chisels driven in with a hammer, the workman watches its progress carefully, and on seeing it deviate from the true cleavage, he draws it back by slightly bending the stronger half. This tendency of the split to 'run out' is strongest in the harder 'veins' or beds and in blocks which have been indurated by proximity to a dyke (a peculiarity known as *hollt gron*, or 'round cleavage'). In this case the quarryman sometimes has to mark or guide the cleavage all round the edge before beginning to open it, especially in cleaving the thickness of two slates. In the softer beds, on the other hand, there is a liability to break in the process of splitting, and the workman is sometimes obliged to use a long flat chisel, or 'driver,' which he forces into the split with a mallet.

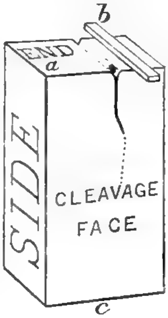
The successful splitting of the slate-rock depends on its possessing a

[1] *Geol. Mag.*, 1884, p. 269.

certain degree of flexibility, and to this flexibility the 'quarry water' or natural moisture of the rock is essential. The blocks must therefore be worked while fresh from the quarry; even an exposure of a day or two makes an appreciable difference in the facility of cleavage, and in dry weather the men are careful to keep the blocks well watered. The softest rock, which is the easiest to cleave when fresh, becomes the most difficult if allowed to dry.

The tendency of the split to 'run out' to the face of the slate and the manner in which it can be drawn back are instances of the fact which we have found to be a necessary consequence of the mechanical theory, viz., that the rock will split at a small angle with the true cleavage-planes under the action of suitable stresses. It is well known that a 'false cleavage,' slightly oblique to the direction of the true, is often obtained. Such is the case on the faces of the blocks when they are roughly split off with a thick chisel and hammer. In blasting, too, the fracture is commonly slightly oblique to the true cleavage direction, and often curves away from it at a considerable angle in the neighbourhood of a 'fast' foot-joint. In these cases the surface of the false cleavage is *not* a rough surface consisting of portions of successive true cleavage-planes, but a surface as smooth as that of an ordinary slate.

FIG. 10.



With reference to the so-called 'secondary cleavage' parallel to the 'side,' the mode of treating the blocks of slate-rock in the quarries is again instructive. In cutting a block lengthwise, parallel to the 'side,' a tendency to 'run out' towards one side may be shown (fig. 10). To bring back the crack, a flat bar of iron (*b* in the figure) is laid across the end, near the groove and towards the weaker side, and this is struck with a hammer. The effect is to bring back the crack as shown by the dotted line. This is the most approved method; the old-fashioned plan was to place a lump under the block, immediately below the crack (at *c*), and then to strike with a mallet on the upper end, at the corner (*a* in fig.) next the stronger side. This was less accurate than the other method described, besides presenting the danger of breaking the block at the corner struck. It is easy to see why the deviation of the cut in this case should be greater than that of the 'false cleavage,' for (referring to fig. 5) though the tendency to split along the 'side' is a maximum among all planes parallel to the axis *c*, the maximum is much less sharply defined than in the case of the cleavage proper. The face of a fracture parallel to the 'side,' also, is much less smooth and regular than a cleavage face, and is frequently fluted and grooved. Indeed, it may safely be asserted that no evidence of anything that can fairly be described as a second cleavage is to be found in the slate workings of North Wales. The structure known as 'cross-cleavage,'[1] the *gwniad* of the quarrymen and the 'lace' of slate merchants, which renders worthless much otherwise valuable rock, is only a system of secret jointing.

M. Jannettaz,[2] however, asserts that the *longrain* of the Ardennes slates is a true second cleavage, but it is not quite clear in what sense he employs this term.

[1] Davies, *Slate and Slate Quarrying*, 2nd ed., pp. 25, 48, 49, &c. (1880).

[2] *Bull. Soc. Géol. Fran.* sér. 3, t. xii. p. 211 (1854). Cf. Sedgwick, *Synops. Brit. Pal. Rocks*, Introd. p. xxxv. (1855).

VII. *Spurious and Incipient Cleavages.*

In a paper read before the British Association in 1857, Dr. Sorby[1] put forward what may be regarded as a limitation of his original theory of slaty cleavage. He showed that besides the structure contemplated in his earlier papers, which is 'quite independent of any actual fractures or breaks of continuity, and may be called *ultimate-structure*-cleavage,' there is also 'a cleavage due to very close joints, often so close as to be quite undistinguishable unless a thin section is examined with the microscope, whilst the arrangement of the particles in the spaces between them is independent of the direction of the joints, and is often related to quite another plane. This kind of cleavage may therefore be called *close-joints*-cleavage. The distinction thus enforced is abundantly confirmed by the microscopic study of various slate-rocks, and we shall therefore find it convenient to use the term *cleavage* in a sufficiently wide sense to include not only the structure we have discussed above under the name *slaty cleavage proper*, but also other structures, which, though effectively identical with it, have arisen in a different manner.

In fact Professor Heim, in his comprehensive work 'Ueber den Mechanismus der Gebirgsbildung,'[2] distinguishes three types of cleavage, which, however, may, and frequently do, occur in conjunction:

(i.) Cleavage produced by a succession of displacements or minute faults, resulting from small contortions; this he calls *Ausweichungsclivage.*

(ii.) Cleavage produced by the individual particles of the rock being flattened or elongated perpendicularly to the direction of maximum pressure; this is *Mikroclivage.*

(iii.) Cleavage produced by a parallel arrangement of all the flat and elongated constituents of the rock; to complete the terminology this might appropriately be styled *Fluidaltexturclivage.*

This last type of cleavage is that originally described by Dr. Sorby; the *Mikroclivage*, characteristic of limestones and similar rigid rocks, is that more particularly emphasised by Mr. Sharpe; while the *Ausweichungsclivage* is the structure, or rather the set of allied structures, which we have now to discuss, and which includes the 'close-joint-cleavage' mentioned above. It includes also those structures in which parallel planes of weakness (not actual discontinuity) occur in a rock at certain finite distances apart. If there be actual surfaces of disruption, there may or may not be appreciable displacement along them; the former case presents a series of minute reversed faults of very steep hade. They are, of course, 'close,' as distinguished from open joints, and they may subsequently become sealed up, either by mere cementation or by actual foliation taking place along them. If they thus become obsolete as surfaces of weakness in the rock, there may even be produced by subsequent changes a second cleavage cutting across the first, a result which we have seen to be impossible with true slaty cleavage.

Ausweichungsclivage assumes locally many curious forms, and these structures are met with on very various scales of magnitude, being sometimes very minute, at other times readily detected by the naked eye, when

[1] 'On Some Facts connected with Slaty Cleavage,' *Brit. Assoc. Rep.*, 1857, Trans. Sect. p. 92. Cf. President's Address to Geological Society, 1880, 'On the Structure and Origin of Non-Calcareous Stratified Rocks,' *Quart. Journ. Geol. Soc.*, vol. xxxvi. p. 72.

[2] Band ii. s. 49–58 (1878).

the term 'cleavage' ceases to be properly applicable to them. The same laws of formation seem to govern the small and the great. Professor Heim in his figure[1] illustrating the passage of an overfold into an overfault by the obliteration of the middle limb gives the scale as '$\frac{200}{1}$ to $\frac{1}{10000}$ of the natural size.' Some of the *macro*-structures analogous to this type of cleavage may therefore be found worthy of note.

First, however, it may be remarked that that flattening and elongation of the individual particles of the rock, which constitutes *Mikroclivage*, has its counterpart in the similar distortion of fossils, nodules, and pebbles; and where pebbles or other fragments of visible dimensions make up the bulk of a rock which has yielded uniformly under pressure, we have, in the flattened pebbles &c., a representation on a large scale of the micro-structure of slate as pictured by Mr. Sharpe. A cleaved conglomerate of this kind was long ago noticed by Professor Ramsay[2] at Llyn Padarn. It consists of 'slaty pebbles in a slaty matrix.' A similar rock, in which both pebbles and matrix are apparently compacted volcanic ash, occurred to me in the Boulder-clay at Nantlle. In this specimen the closely-packed pebbles are all strongly distorted in the same directions into approximately ellipsoidal forms. They are all very nearly of the same shape, the ratios of the axes of the ellipsoid being about 1·6 : 1·0 : 0·23, which figures are very nearly the same as those for the green spots in the slates of the district. Numerous examples of distorted pebbles in conglomerates occur in the eastern states of America;[3] the remarkable squeezed conglomerates of the Bergen peninsula have been well described by M. H. H. Reusch.[4] In such cases the pebbles are either so closely packed as to be in contact with one another or, as in the case of the Welsh conglomerates, the pebbles and matrix are about equally hard, and so yielded equally to pressure.

Another type of what we may call *macro*-cleavage corresponds to the structure produced by the parallel flakes of mica in the Llanberis slates; the difference being that in this case the flakes are less minute, and have had an original arrangement parallel to the laminæ of stratification. The laminæ are thrown into a series of small contortions in such a manner that the flakes of mica lie chiefly along certain definite parallel planes oblique to the general direction of stratification, which thus become planes of easy fracture or 'cleavage.' This kind of structure forms a connecting link with *Ausweichungsclivage*, to which type, indeed, it is referred by M. Reusch,[5] who gives a good example from the black, micaceous clay-slates of the Bergen district. In his figure the pseudo-cleavage-planes appear to be about $\frac{1}{8}$-inch apart, and this interval is determined by the scale of the small contortions.

As an example of true *Ausweichungsclivage* arising from minute and regular contortions, I may instance a black slate-rock from the pass of Drws-y-Coed, near Snowdon. In this rock the contortion has taken

[1] *Op. cit.* Atlas, Taf. xv., fig. 14.

[2] *Mem. Geol. Surv. Gr. Brit.*, vol. iii., 'Geology of North Wales,' p. 179, 2nd ed. (1881).

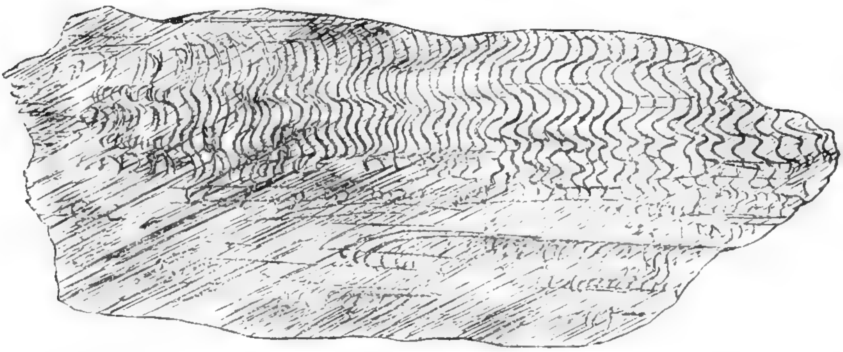
[3] Hitchcock, Crosby, Wadsworth, &c. For references, see *Proc. Bost. Nat. Hist. Soc.*, vol. xx. pp. 308 *et seq.* (1879).

[4] *Silurfossiler og Pressede Konglomerater i Bergenskifrene*, 1882; German trans., *Die fossilienführenden krystallinischen Schiefer, &c.*, S. 22, 51, figs. 11, 12, 33, 37 (1883), Leipzig.

[5] *Op. cit.*, S. 51, fig. 32.

place in a more symmetrical manner than in the last-named, so that the resulting 'cleavage-planes' are perpendicular to the general direction of stratification. The interval between them is from $\frac{1}{8}$ to $\frac{1}{4}$-inch (fig. 11), but there is also some tendency in the intermediate parts of the rock to

FIG. 11.



× $\frac{1}{2}$.

split in the same direction. This is explained by a microscopic examination, which reveals that, besides the contortions mentioned, there is also a system of much smaller contortions, which give rise in like manner to a set of less pronounced cleavage-planes at distances of from $\frac{1}{50}$ to $\frac{1}{100}$-inch apart (fig. 12). If the rock be split along the bedding, which is easily done, these microscopic contortions are seen as fine striæ marked on the surface of the larger flutings, and having the same direction. The larger contortions in this rock, and the resulting 'cleavage' may be compared with an example figured by Professor Heim.[1]

FIG. 12.

× 25.

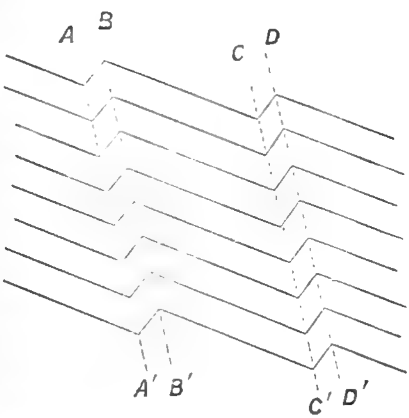
When a rock-mass becomes contorted by the action of pressure, it usually yields in such a manner that the contortions into which the planes of stratification, or any pre-existing planes, are thrown, are of an undulating form. It seems, however, that, under certain circumstances, zigzag, instead of undulating, contortions are produced, the crests and troughs of the contortions being not curved but more or less sharply angled, as in fig. 13. Here a shearing motion has taken place in the direction parallel to AA′ and BB′, but such shearing has occurred only in certain parts of the mass, such as those between AA′ and BB′, or between CC′ and DD′, while the other parts, such as those between BB′ and CC′, have not been affected. In the kind of contortions considered,[2] each zigzag is usually unsymmetrical, having a long and a short limb. Excellent

[1] *Op. cit.*, Atlas, Taf. xv., fig. 11.
[2] Cf. Stapff, *Neu. Jahrb. für Min., &c.*, 1882, Bd. i. S. 75.

examples, associated also with curved and irregular contortions, are met with in what Professor T. McK. Hughes[1] calls the 'gnarling' of the perplexing beds about Amlwch in the North of Anglesey. Some of these are figured in the Survey Memoir on North Wales.[2] In this case, if, as Professor Ramsay supposes, the planes such as AA′ in fig. 14 indicate the original stratification of the rocks, and the zigzag planes represent an obsolete cleavage, the shearing has taken place along the bedding, and has affected certain beds to the exclusion of others. Professor Liversidge[3] has described and figured a slate-rock in which the undoubted cleavage-planes are thrown into well-defined acute zigzags by subsequent contortion.

To return to *Ausweichungsclivage*, it is evident that planes like AA′ and BB′ in fig. 14, passing through the angles of the zigzag contortions, must be planes of structural weakness in the rock, even though no actual disruption of the laminæ of stratification may have occurred at the places where they are sharply bent. M. W. C. Brögger[4] states that such planes of weakness, which he terms *Knickungsebene*, are common in the friable, finely laminated beds of his Silurian Etage 2 in the Christiania district. I have noticed a dark shale at Porthwen on the north coast of Anglesey, in which the laminæ of stratification, marked by graptolites, are thrown into sharply defined zigzag contortions, the longer and shorter limbs of which are about 2 inches and $\frac{1}{4}$-inch respectively, in length. A similar instance is figured by M. Reusch[5] from Döbeln in Saxony. These rocks are readily fractured along the *Knickungsebene*.

Fig. 13.



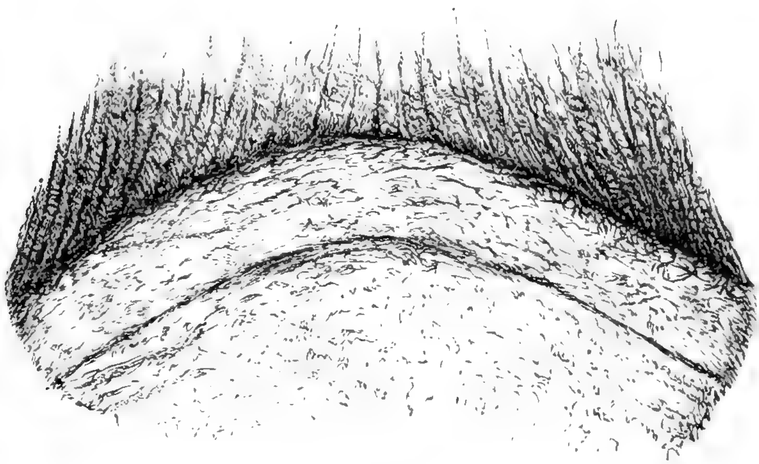
Lastly, there is the variety of *Ausweichungsclivage*, in which the 'cleavage-planes' are actual surfaces of discontinuity in the rock—in fact, minute faults. Prof. Heim regards the faulting in this case as a further stage of unsymmetrical contortion of the laminæ of bedding, so that the dislocations are of the kind which he names *fold-faults* (*Faltenverwerfungen*), as distinguished from the ordinary *fissure-faults* (*Spaltenverwerfungen*). Examples on a microscopic scale are not uncommon: the 'gnarled beds' of Amlwch[6] afford a beautiful instance (fig. 14). As seen in the figure, the faults are related to the visible contortions of the rock, being roughly parallel to the axial planes of the zigzags or contortions (the apex of one of which is shown in the figure), but curving away upon reaching a felspathic layer, through which they do not pass. It is indeed evident that the faults could not be perpendicular to the direction of the lateral pressure which produced them. In accordance with what might

[1] *Quart. Journ. Geol. Soc.*, vol. xxxvi. p. 237 (1880).
[2] *Mem. Geol. Surv.*, vol. iii. pp. 237–240, figs. 91–96, 3rd ed. (1881).
[3] Paper read before Roy. Soc. New South Wales, December 6, 1876.
[4] *Die silurischen Etagen 2 und 3 im Kristianiagebiet, &c.*, S. 216 (1882), Christiania.
[5] *Op. cit.* S. 52.
[6] [Some slides of the Amlwch rocks show very clearly the passage of an 'overfold' into a 'fold-fault,' as described by Heim.]

be expected, the hade of the faults, measured from the axial plane, becomes less as we approach that plane, and the throw of the faults diminishes also. These faults are on an average about $\frac{1}{350}$-inch apart; a cleavage-structure on a like scale, and showing altogether very similar appearances, has been figured by Prof. Heim.[1] Owing to subsequent actions, the Amlwch rock shows no marked tendency to split in the direction determined by this microscopic faulting, but on examining one of the contorted surfaces of 'foliation,' the traces of the minute faults are visible as a very fine striation running parallel to the strike of the contortions.

Dr. Sorby,[2] in his Presidential Address to the Geological Society in 1880, described and figured an interesting case of cleavage due to close parallel planes of discontinuity in slate-rock at Liskeard, the planes being apparently about $\frac{1}{300}$-inch apart. This instance is instructive, because in the less disturbed parts of the same rock, where the cleavage is very imperfect, the earliest stage of the structure is seen in the shape of minute

FIG. 14.



×25.

contortions of the laminæ of stratification. He also pointed out that in some other cases, such as the pencil-rock of Shap, the effect of lateral pressure has apparently been to break up the laminæ of deposition in an irregular manner, so that the laminated structure is almost obliterated, and the microscopic flakes of mica, which constitute nearly the whole mass of the rock mentioned, are practically inclined about equally in all directions. This removed a difficulty which had previously been felt with regard to his original theory of slaty cleavage, viz., the postulate that the rocks which now form roofing slate had, prior to their becoming cleaved by lateral compression, &c., a structure in which the flat constituent particles were not arranged in laminæ of deposition, as is commonly the case in uncleaved shales, &c., but distributed at random in all positions. Dr. Sorby[3] had formerly endeavoured to account for this assumed original structure of slate-rock by the supposition that the microscopic flakes of mica in it were of secondary origin; but we now see that the required arrangement might be brought about by the earlier effects of

[1] *Op. cit.*, Taf. xv., fig. 8. [2] *Quart. Journ. Geol. Soc.*, vol. xxxvi. Proc. p. 73.
[3] *Brit. Assoc. Rep.*, 1857, Trans. Sect. p. 92.

the same lateral pressure which, as a final result, produced the cleavage structure in the manner described in preceding sections. This supplementary hypothesis therefore must be regarded as an essential part of the mechanical theory of slaty cleavage.

It appears from the above remarks that a system of close parallel planes of discontinuity in a rock, though lacking many of the characteristics of slaty cleavage proper, may be in general effect very similar to it; and, again, that such a structure may be itself a first step towards the true slaty cleavage. Such planes of discontinuity, however, are not properly speaking joints, but rather small faults. They are due to lateral pressure, and their distance apart is determined by the dimensions of the small folds which are a first step towards the faulting. True joints, on the other hand, although, as in the case of the 'cleat' of coal, they may be very close together, must be ascribed proximately to lateral tension, and their distance apart seems to be regulated by the lithological character of the rocks in which they occur,[1] and doubtless also by the thickness of the beds which they traverse.

If, however, a rock having originally a true jointed structure be subsequently subjected to lateral pressure, it may fairly be supposed that this pre-existing jointing will affect the results of the pressure. Thus, unless the direction of the pressure be nearly perpendicular to the joints, the rock may conceivably begin to yield by sliding along the joint-planes, which thus become small reversed faults, and the subsequent effects of the pressure on the rock may be modified accordingly. This point is emphasised by Professor W. King,[2] who, however, makes it the starting-point of a general theory of slaty cleavage, in which he will probably have few followers. Stated in his own words, his thesis is that 'Slaty cleavage is essentially the result of pressure exerted against divisional planes, chiefly belonging to jointing, that existed in any given rock prior to its becoming affected by such pressure.' But there seems to be no evidence to show that jointing or any other special structure is a necessary preliminary to cleavage, and it is yet to be proved that the direction of the cleavage-planes produced in a rock by lateral pressure is in any way dependent on those pre-existing planes of weakness, which we should naturally expect would be obliterated as such by the action of the pressure itself.

In connection with the subject of jointing, it may be noted that many of the recorded instances of a second direction of cleavage in rocks are due to a confusion between cleavage and fine lamellar jointing.[3]

VIII. *Comparison of the Cleavage- and Fluxion-structures.*

We shall find it convenient to use the term *fluxion-* or *flow-structure*[4] in a wide sense, to embrace all those structures, whether macroscopic or

[1] Phillips, *Illustrations of the Geology of Yorkshire*, pt. 2 (1836); London. Fisher, *Geol. Mag.*, 1884, p. 211.

[2] 'Report on the Superinduced Divisional Structure of Rocks, called Jointing, and its Relation to Slaty Cleavage,' *Trans. Roy. Irish Acad.*, vol. xxv. Sci. p. 605 (1875). *An Old Chapter of the Geological Record, &c.*, Appendix, p. 107 (1881).

[3] MacCulloch, *Introduction to Geology*, new ed. (1833). Sharpe, *Quart. Journ. Geol. Soc.*, vol. v. p. 115 (1849). De la Beche, *Geological Observer*, pp. 712, 713 (1851). Nicol, *Quart. Journ. Geol. Soc.*, vol. xv. p. 113 (1859). Davies, *Slate and Slate Quarrying*, pp. 25, 48, 49, 2nd ed. (1880), &c.

[4] *Bewegungs-Phänomen* (Weiss, 1866), *Fluidal-Textur* (Vogelsang, 1867), *Fluctuations-Textur* (Zirkel, 1867).

microscopic, consequent upon a flowing motion of a mass of any material. The comparison between slaty cleavage and the various types of fluxion-structure met with in different rocks has been made by Mr. Poulett Scrope and others.[1] The movement which the parts of a rock experience under the action of the forces which produce slaty cleavage may evidently be regarded in the light of a flowing motion along the cleavage-planes in the direction of their dip, and so is analogous to the similar flowing of other plastic materials, such, for instance, as a viscous lava.[2] Thus the rearrangement of the ultimate fragments of a slate-rock in the general direction of the 'grain' or cleavage-dip corresponds to the arrangement of the microlites in a rhyolitic or andesitic lava parallel to the lines of flow: the distortion of fossils, &c., in the slate is analogous to the drawing out of vesicular cavities in the lava into amygdaloidal or ellipsoidal forms: the more resisting fossils, around which the cleavage is slightly curved, are paralleled by the porphyritic crystals in the lava, round which the lines of flow sweep in curves: and, finally, both the fossils in a cleaved rock and the porphyritic crystals in a lava are occasionally found to be shattered and the fragments drawn apart in the direction of flow. Fluxion structure, in its various phases, is moreover common, though local, in plutonic, as well as volcanic rocks; and where a rock is largely made up of parallel tabular or linear crystals of such minerals as felspar, &c., it is not infrequently found to possess in consequence a kind of rude macro-cleavage, either lamellar or fibrous, in the direction so determined.

This 'parallel-structure,' to be clearly distinguished from foliation on the one hand and from platy jointing on the other, was long ago remarked by various geologists;[3] the 'grain' in certain Cornish granites, described by Professor Sedgwick[4] is a structure of this character. In rocks which have a large proportion of isotropic ground-mass, the fluxion-structure does not produce any marked tendency to split parallel to it.

Hitherto we have spoken of the flowing of igneous rocks only when in a partially molten condition; but the comparison may be carried much further. Since the experimental researches of M. Tresca[5] the flowing of solid bodies is no longer a contradiction in terms, and of recent years the plasticity of rock-masses has been the subject of much discussion.[6] In greatly disturbed regions even the hardest rocks are found to have suffered a mechanical deformation, which is in part of the nature of

[1] Scrope, 'On Lamination and Cleavage Occasioned by the Mutual Friction of the Particles of Rocks while in Irregular Motion,' *Quart. Journ. Geol. Soc.*, vol. xv. p. 84 (1859). *Geologist*, vol. i. p. 361 (1858). Heim, *op. cit.*, Bd. ii. S. 56.

[2] Cf. Miller, 'Fluxion-structure in Till,' *Geol. Mag.*, 1884, p. 472.

[3] Von Buch, Scrope, &c. For the earlier notices of both parallel structure and gneissic structure in igneous rocks, see Naumann, 'Ueber die wahrscheinlich eruptive Natur mancher Gneisse und Gneiss-Granite,' *Neu. Jahrb. für Min., &c.*, 1847, S. 297; trans. in *Quart. Journ. Geol. Soc.*, vol. iv. pt. ii. p. 1 (1848).

[4] *Trans. Geol. Soc.*, 2nd ser., vol. iii. p. 483 (1835). Introduction to *Synopsis of British Palæozoic Rocks*, p. xxxiv. (1855).

[5] *Comptes Rendus*, 1864, p. 754; 1865, p. 1228; 1867, p. 809. *Mém. Savants Etrangers*, vol. xviii. p. 733; vol. xx. p. 75. *Sur l'écoulement des solides*, 1872, Paris. 'Flow of Solids,' *Proc. Inst. Mech. Eng.*, 1878, p. 301.

[6] Heim, *Ueber den Mechanismus der Gebirgsbildung*, 1878, Basel; *Zeitsch. Deutsch. Geol. Gesellsch.*, Bd. xxxii. S. 262 (1880). Stapff, *Ueber die Plasticität der Gesteine beim Zusammenpressen, &c.*, *ibid.*, 1879, S. 292, 792; 1881, Bd. i. S. 185. Pfaff, *Der Mechanismus der Gebirgsbildung*, 1879, Heidelberg. Lehmann, *Entstehung der Altkrystallinischen Schiefergesteine, &c.*, 1884, Bonn.

flowing. In describing the phenomena in the neighbourhood of the great 'thrust-planes' of Eriboll, the officers of the Geological Survey [1] repeatedly make use of the expression 'fluxion-structure' as one specially applicable to the result of a shearing motion in the rocks. According to the character of the rocks affected and the intensity of the forces to which they have been subjected, the deformation of the mass appears to have proceeded partly by internal fracture and faulting of the rocks, and partly by their gradual and continuous distortion in the manner of plastic bodies. In fact, continuous and disruptive movements seem to have taken place concurrently, in such a way that the planes of shearing with the consequent 'grain' or fluxion-structure are not always distinguished from planes of abrupt slipping with their associated slickensides. A characteristic of these intense mechanical changes is that they are frequently accompanied, and their results complicated, by the paragenesis, recrystallisation or destruction of some of the constituent minerals of the rocks and the production of new ones. In this way foliation and gneissic structure may be produced as the result, partly of mechanical, partly of mineralogical and chemical agencies. Apart from these last, however, the plastic movement or flow, which in a crystalline rock gives rise to foliation, is precisely analogous to that which in a clastic rock produces slaty cleavage; and in fact where rocks of the required lithological types are found associated together and affected by the same movements, the foliation of the one passes into the cleavage of the other. As, moreover, the development of new minerals takes place on the cleavage-planes of the latter as well as on the foliation-planes of the former, it is impossible to draw any line of demarcation between the two structures. As instances of foliation associated with, and in part at least produced by, mechanically caused movements, we may cite the hornblende-schists of the Bergen peninsula and the Saxon Erzgebirge, and the granulites, and probably in part the gneisses of the latter region. An instance on a small scale has been described by Mr. Teall in a dyke at Scourie, Sutherland, where the conversion of dolerite into hornblende-schist is clearly exhibited.

By regarding cleavage and some cases of foliation in the light of fluxional structures, we gain a clue to some of the difficulties connected with those phenomena. The segregation of the several constituents into lenticular patches is a peculiarity of some types of foliation, and, indeed, in some gneisses, presents a very characteristic appearance. Now it is a matter of common observation that a 'stream of liquid moving in any general direction tends to divide itself, more or less, into veins and threads composed of particles of different degrees of coarseness, and, consequently, of different degrees of mobility, and moving at different rates.' The significance of this was pointed out by Mr. Poulett Scrope [2] in connection with his theory which made the foliation of gneiss and mica-schist an original structure produced during the protrusion of an igneous mass in a partially molten state, and the same principle would probably have at least a limited application to the flow of solid rock masses which gives rise to the foliation or fluxion structure in the Eastern gneiss of Sutherland and other rocks of like character. Whether the segregation in these cases is to be referred in any measure to the cause described, or whether it is

[1] Geikie, Peach, and Horne, *Nature*, November 13, 1884. Cf. Lapworth, *Geol. Mag.*, March 1885, p. 97.

[2] *Geologist*, vol. i. p. 363 (1858). See also *Quart. Journ. Geol. Soc.*, vol. xii. p. 345 (1856).

due solely to the action of molecular forces, which would probably be intensified by the extreme pressure, is one of the questions which must be left for further elucidation.[1] But as bearing upon this question, and as showing that it is a speculation by no means foreign to the subject of slaty cleavage proper, we may notice the interesting case described and figured by Professor Bonney,[2] of a 'structure imitative of foliation produced by pressure on a stratified rock without important mineral change.' Here, in a cliff section at Torcross, South Devon, are alternate layers of fine dark mud and silt, the former predominating, which are much folded, and consequently inclined at various angles to the cleavage which traverses the whole. Where the cleavage and bedding coincide, the layers, though much compressed, are distinct; but where the angle between the direction of pressure and the normal to the surface of the bed has been a large one, the stripe is obscured or obliterated, and a new structure produced. The broader gritty bands have their edges 'frayed out,' or send out comb-like processes into the finer bands in the direction of the cleavage; the narrower bands are entirely obliterated and replaced by a new structure of parallel lenticular streaks or elongated 'eyes' extending in the direction of the cleavage.

Connected with the tendency of a heterogeneous mass in flowing motion to separate into layers or patches is its liability to unsteady or sinuous motion. The very tortuous fluxion structure exhibited by many rocks of volcanic origin must be ascribed to this circumstance. As Mr. Poulett Scrope[3] remarked with reference to the ribboned and banded trachytes, &c., the contortions are owing to 'the various degrees of mobility of the different layers, those of coarser grain . . . retarding the motion of the proximate layers which possessed a greater liquidity.' In fact, the resistance to motion within a moving mass of the kind considered would be more of the nature of surface friction than of viscosity, and so would be a condition unfavourable to steady motion.[4] A similar explanation may apply to those cases in which contorted foliation is attendant upon the fluxional motion of rock masses.[5] Such contortions occur, it should be noticed, both along the dip and along the strike of the foliation.

The constant association of intense mechanical deformation and crushing of rocks with molecular and atomic changes of a certain character naturally leads to the inquiry, what is the nature of their connection, and to what extent can the two phenomena be supposed to have a common origin? In fact, in what measure the intense lateral pressure which we assume to have been the agent by which a fluxional structure was impressed upon solid rock masses, may be held to account for concomitant changes of a mineralogical and chemical kind. Some materials for such an inquiry will find their place in the following section.

But to prevent misconception, I must point out at this stage, that in the present paper, foliation, except in so far as it is related to cleavage, has no proper place. Our subject embraces only those types of structure

[1] Cf. Lehmann on the 'Augengranulites' of Saxony, *op. cit.*, S. 202 *et seq.*

[2] *Quart. Journ. Geol. Soc.*, vol. xl. pp. 18 *et seq.*

[3] *Trans. Geol. Soc.*, 2nd ser., vol. ii. p. 195 (1826).

[4] Osborne Reynolds, 'An Experimental Investigation of the Circumstances which Determine whether the Motion of Water shall be Direct or Sinuous, &c.,' *Proc. Roy. Soc.*, vol. xxxv. p. 84 (1883).

[5] Cf. Fisher, *Physics of the Earth's Crust*, p. 124 (1881), London.

which are clearly referable, in whole or in part, to the action of mechanical forces. With the views of those geologists who ascribe the formation of certain schists to unique physical conditions prevailing in Pre-Cambrian times, we are in no wise concerned. Neither is it within the province of this paper to discuss superinduced foliation on pre-existing structural planes in a rock. We will only remark that such foliation in a stratified rock may apparently be produced upon any kind of structural planes previously existent in the rock, whether of lamination, bedding, current-bedding, cleavage, or jointing; and that the foliation will follow whichever of these sets of planes is the most pronounced, according to Forbes's law of 'least resistance.' Further, such superinduced foliation may apparently be formed upon structural planes in a crystalline rock. Referring to the central portion of the Alps, Professor Bonney[1] says: 'The gneissic mass has been crushed, cleaved, and on the cleavage planes films of a hydro-mica have been developed. We cannot fail to be struck, when once our eyes have been opened to it, by the frequency of a slabby structure in the more central parts of the Alpine ranges, the surfaces of these slabs being coated with minute scales or films of mica.' These he regards as 'records of a rude cleavage which has been impressed upon the more central and less flexible portions of the Alps during the great earth-movements which they have undergone since they were first metamorphosed.'

IX. *Physical and Chemical Changes dependent on Pressure.*

A simple pressure acting at any point of a mass in a definite direction is mathematically equivalent, as may readily be proved,[2] to (i.) a uniform pressure in all directions, combined with (ii.) certain shearing stresses. The former tends to produce a compression of volume without change of shape, the latter a deformation without alteration of volume. It is then to the latter that the mechanical deformation or fluxion of rock-masses must be attributed; while the former, which is of the nature of a hydrostatic pressure, may prove to have been at least an important factor, if not indeed the prime agent, in the mineralogical and chemical changes observable in the same rocks. We shall therefore, to fix ideas, disregard for the present the shearing stress and the consequent movements of the rock, and consider only that 'quaquaversal' or uniform pressure with which hydrostatical theories render us familiar.

The importance of pressure as an element in the conditions of molecular and chemical changes has from an early date been more or less clearly recognised by geologists as well as physicists. It figures, at least as an accessory, in all modern theories of 'regional metamorphism,' and high pressures play an important part in the experiments of those who have worked at the artificial production of minerals and the imitation of the structures of crystalline schists.

Pressure, however, does not appear to be always ranked in its proper place as a condition, coördinate with temperature, determining the action of all physical and chemical forces; and its importance as such does not seem to be thoroughly realised in the discussion of all geological questions. Indeed we may say with Professor Lehmann[3] that 'we stand at present

[1] *Proc. Roy. Inst.*, vol. xi. p. 64 (1885).
[2] Thomson and Tait, *Natural Philosophy*, vol. i. pt. ii. § 682, new ed. (1883).
[3] *Op. cit.*, p. 244.

only on the threshold of a knowledge of the changes of substances and their effects upon one another under the influence of pressure.' Among those whose experimental researches have added to our knowledge in this line may be mentioned Sir James Hall,[1] Sir William Thomson,[2] Sir D. Brewster,[3] Dr. H. C. Sorby,[4] M. L. Cailletet,[5] Dr. F. Pfaff,[6] and M. Walth. Spring.[7]

Speaking generally, it may be said that the effect of increased pressure is to facilitate such physical and chemical changes as involve a contraction of volume in the substances operated upon, and to retard changes which are accompanied by an expansion. For instance, both theory[8] and experiment[9] show that the melting-point of a solid is raised or lowered by an increase of pressure, according as the substance expands or contracts in melting. Again, the experiments of Dr. Sorby prove that when a salt contracts on passing into solution, which is the case with most known substances, the effect of augmented pressure is to increase its solubility. This fact he has shown[10] to have important bearings in geology, for it follows that where a mass of rock is subjected to unequal pressure, some of the constituents may be dissolved at those points where the pressure is greatest, and redeposited where it is least. In a contorted limestone band among slate-rocks at Ilfracombe, the calcareous matter is seen to have been thus removed from the central portions of the limbs of the folds and collected at their crests and troughs, which suggests another possible explanation for some cases of the obliteration of stratification by pressure and its replacement by lenticular and elongated structures. In a Devonian limestone, too, the stems of encrinites have been partially dissolved on those sides where they were subjected to the greatest pressure, and the crystalline calcite redeposited on those sides where the pressure was least; this observation is of importance in connection with the effects of intense mechanical forces upon the individual crystals and crystalline grains of a rock, which might thus change their form by molecular rearrangement without possessing in themselves the property of plasticity[11] in any degree.

Next, it has been recognised since the classical experiments of Sir

[1] 'Account of a Series of Experiments showing the Effects of Compression in Modifying the Action of Heat,' *Trans. Roy. Soc. Edinb.*, vol. vi. p. 71 (1805).

[2] *Proc. Roy. Soc. Edinb.*, 1850. *Mathematical and Physical Papers*, p. 165 (1882).

[3] 'On the Production of Crystalline Structure in Powders by Compression and Traction,' *Proc. Roy. Soc. Edinb.*, vol. iii. p. 178 (1853).

[4] 'On the Direct Correlation of Mechanical and Chemical Forces,' *Proc. Roy. Soc.*, vol. xii. p. 538 (1863). 'Ueber Kalkstein-Geschiebe mit Eindrücken,' *Neu. Jahrb. für Min., &c.*, 1863, S. 801. Letter to M. Delesse, *Bull. Soc. Géol. Fr.*, sér. 2, t. xx. p. 184 (1862).

[5] 'De l'influence de la pression sur les phénomènes,' *Comptes Rendus*, t. lxviii. p. 395 (1869).

[6] 'Versuche über die Wirkungen des Druckes auf chemische und physikalische Vorgänge,' *Neu. Jahrb. für Min., &c.*, 1871, S. 834.

[7] 'Récherches sur la propriété que possèdent les corps solides de se souder par l'action de la pression,' *Bull. Acad. Roy. Sci. Belg.*, sér. 2, t. xlix. p. 323 (1880).

[8] Professor James Thomson, 'Theoretical Considerations regarding the Effect of Pressure in Lowering the Freezing-point of Water,' *Trans. Roy. Soc. Edinb.*, vol. xvi. p. 575 (1849).

[9] Sir W. Thomson, *loc. cit.*

[10] Presidential Address, *Quart. Journ. Geol. Soc.*, vol. xxxv. p. 88 (1879).

[11] Lehmann, *loc. cit.*, S. 197. Teall, *Quart. Journ. Geol. Soc.*, vol. xli. pp. 139, 140 note (1885).

James Hall, that pressure exerts a modifying influence on the passage of bodies from the amorphous to the crystalline state; the experiments of M. Spring[1] go to establish the law that this change is assisted by increased pressure, when the volume of the substance diminishes in the process of crystallisation.[2] The same observer has shown that substances of almost every kind in the state of powder can be welded into a solid mass by the action of very great pressure without high temperature.

More striking is the effect of pressure upon chemical changes. Dr. Sorby,[3] in 1863, suggested a direct correlation between mechanical and chemical forces, but M. Spring, using much higher pressures, obtained results of a very definite character. He found, for example, that by operating upon a mixture of sulphur and copper filings, with a pressure of 5,000 atmospheres, he obtained crystallised copper sulphide. He laid down the rule that pressure assists those chemical changes which involve a diminution of bulk. The complementary part of this law, that pressure retards or prevents such chemical actions as are accompanied by an increase of bulk, had already been supported by the experiments of M. Cailletet and Dr. Pfaff.

Such facts as the above seem to afford a firm basis for a mechanical theory of metamorphism, applicable to regions which, by their general structure, present evidence of the action of great pressure, but not to be applied to any given district without inquiry into the epoch of the chemical and mineral changes in the rocks, and the possible existence of other metamorphosing agents. For a comprehensive study of a difficult tract of metamorphic rocks from a purely mechanical standpoint we may go to Dr. Lehmann's work on the 'Saxon Granulitgebirge,' referred to above.

Viewing the matter in the most general way, we may start from the axiom that both physical and chemical forces are controlled by two conditions—temperature and pressure. Wherever we see evidence of changes in rock-masses other than those now in progress among surface rocks, we may infer the operation of either extreme temperature or excessive pressure, or both these conditions in conjunction, and the decision must depend on a full consideration of the facts. Experiment shows that in certain cases of physical and chemical changes, elevated temperature and increased pressure tend in the same direction, while in others they conflict. In the latter case, had we sufficient data, we should obtain a crucial test as to which of the two agencies has been answerable for the changes in question; but for this purpose we must await further evidence from the laboratory. It may, however, be safely affirmed that some of the mineral changes evinced in the districts we have mentioned cannot credibly be referred to the effects of high temperatures, and are even the reverse of those changes which we know to be ordinarily produced by heat. For instance, the conversion of augite and diallage into hornblende is a fact witnessed to by several observers;[4] but at ordinary pressures fused hornblende recrystallises in the form of augite.[5] The

[1] *Loc. cit.*

[2] As an example of this principle, compare a holocrystalline with a vitreous rock of similar chemical composition; the former, produced under great pressure, is *denser* than the latter, which consolidated at an ordinarily low pressure.

[3] *Proc. Roy. Soc.*, cit. sup., p. 546.

[4] Reusch, Lehmann, Teall, &c., *loc. cit.*

[5] Rose, *Pogg. Ann.*, vol. xxii. p. 338 (1831). Fouqué and Michel-Lévy, *Synthèse des Mineraux et des Roches*, 1882.

formation of white mica and quartz by the destruction of orthoclase is probably another significant metamorphosis; muscovite, like hornblende, has never been reproduced artificially. The mode of occurrence of hydrous micas, frequently associated with slickensides and other immediate evidences of stress, seems to point to the importance of mechanical forces in their genesis. Professor Bonney[1] considers that 'these filmy minerals appear to be very readily formed under pressure from damp argillaceous material in a state of fine division,' and is of opinion that 'perhaps it is hardly too much to say that the difference between a satiny slate or phyllite and an ordinary shale is due even more to the action of pressure than to mineral composition or geological age.' The same authority, however, insists on an essential distinction between such rocks and true schists, which latter, he maintains, require for their production something more than mechanical forces.

In weighing the relative importance of the results of mechanical stress on the one hand, and the more direct effects of the central heat of the earth on the other, it must not be overlooked that not only increased pressure, but also rise of temperature may result from the former agency. 'The heat produced locally within the crust of the earth by transformation into heat of the mechanical work of compression, or of crushing of portions of that crust,' as in Mr. Mallet's[2] experiments, has been invoked by Professor Prestwich,[3] in a recent paper, as a factor of the first importance in the metamorphism of certain regions, such as the Appalachian Mountains and the Ardennes. This transformation of the mechanical work done by pressure into heat is, of course, quite distinct from the *direct* effects of pressure on physical and chemical forces discussed above. The latter necessitates no rise of temperature, but involves an immediate correlation between mechanical work and the energy of molecular and atomic forces.[4] The heat in the former case, moreover, would arise partly from the hydrostatic pressure and consequent compression, partly from the shearing stress and associated deformation; and in hard rocks the latter would doubtless be of the most importance. It seems reasonable to suppose, then, that the work done upon a rock by a lateral pressure to which it yields is expended in three ways—viz., in producing deformation of the rock mass both by plastic shearing and by fracture, in bringing about molecular and chemical changes in its composition, and in generating heat, which will again give rise to changes not always of the same kind as the former. The proportion of the available energy devoted to each of these effects must naturally depend upon the nature of the rocks operated upon.

Considerations such as these may perhaps serve in some measure to lessen the difficulties that beset the study of cleavage and foliation by referring apparent anomalies to the different lithological characters of the rocks affected. Thus in Mr. Teall's[5] dolerite dyke molecular rearrangement is seemingly an earlier effect of the forces concerned than foliation-structure, while, in Professor Bonney's Torcross section, the reverse is the case. In an originally soft rock, a deformation or flowing, with its

[1] *Quart. Journ. Geol. Soc.*, vol. xl. pp. 18, 25, 26 (1884).

[2] 'On Volcanic Energy,' *Phil. Trans.*, vol. clxiii. p. 147 (1873). Cf. Daubrée, *Études Synthét. de Géol. Expérim.*, p. 448 *et seq.* (1879), Paris. *Bull. Soc. Géol. Fr.*, 1878, p. 550.

[3] *Roy. Soc.*, June 18, 1885. *Nature*, July 2.

[4] Sorby, *loc. cit.*

[5] *Loc. cit.*, pp. 139, 142.

attendant phenomena, would doubtless be the first effect of lateral pressure, while a more intense application of stress might induce mineral changes of the nature already alluded to. Thus it may, according to some speculators, be possible to bridge over the differences between schists and gneisses of certain types, on the one hand, and satiny slates or phyllites on the other, while between the latter and ordinary slates every gradation may be found.

In this way we arrive at Dr. Darwin's[1] theory that 'in most cases foliation and cleavage are parts of the same process; in cleavage there being only an incipient separation of the constituent minerals; in foliation a much more complete separation and crystallisation;' or, again,[2] 'that the same power which has impressed on the slate its fissile structure or cleavage has tended to modify its mineralogical character in parallel planes.' This may be compared with the hypothesis of Mr. W. Hopkins,[3] that slaty cleavage is the result of molecular forces, but has its direction determined by mechanical stress. Dr. Darwin apparently supposed that the mechanical force was not only a directing influence, but also the prime cause of the molecular actions. In so far as this is a return to the purely crystalline theory of slaty cleavage, as advocated by Professor Sedgwick, the mass of evidence referred to in the preceding sections must compel us to pass it over; but we may reconcile Dr. Darwin's valuable observations with the theories of Dr. Sorby and others, by admitting that many of the rocks which we call slate have experienced a development of new minerals (such as micas, chlorites, and epidotes) concurrently with the production in them of the cleavage structure, and that there appears to be a passage from such rocks into mica-schist and foliated gneiss. In fact, it seems probable that if the term cleavage be applied only to rocks in which no mineral changes are to be detected, the class of cleaved rocks will be much reduced in size; and, further, that if we ascribe all such mineral changes in slates to subsequent foliation on cleavage planes, the number of our metamorphic regions will be greatly augmented. In North Wales, for instance, Professor Sedgwick[4] described the cleavage planes of the slate as 'coated over with chlorite and semicrystalline matter, which not only merely define the planes in question, but strike in parallel flakes through the whole mass of the rock.' From the microscopic examination of the same rocks, Dr. Sorby[5] regarded the minute scales of mica which make up a large part of the mass, and resemble in structure 'pseudomorphs of mica or chlorite after felspar' as being of secondary origin; and although he apparently considered the origin of these scales anterior to the cleavage structure, he stated that these so-called clay slates are 'analogous to very fine-grained mica-schist, into which they gradually pass by the increase in the size of the crystals of mica.' In the roofing slates of other districts there is often evidence of mineral changes which appear to have been contemporary with the cleavage.

In leaving this part of the subject, we may remark that certain other theories, not otherwise of much interest, have linked together cleavage and foliation under a common explanation. Professor H. D. Rogers,[6]

[1] *Geol. Obs. in South America*, p. 166 (1846); 2nd ed. p. 466 (1876).

[2] *Ibid.* p. 163; 2nd ed. p. 462.

[3] *Camb. Phil. Trans.*, vol. viii. p. 456 (1849). Cf. also the cautious statement of Mr. Jukes quoted in the first section of the present paper.

[4] *Geol. Trans.*, ser. 2, vol. iii. p. 471 (1835).

[5] *Brit. Assoc. Rep.*, 1857, Trans. Sect., p. 92.

[6] *Trans. Roy. Soc. Edinb.*, vol. xxi. p. 471 (1856).

endorsing with modification Professor Sedgwick's crystalline theory, held that 'both cleavage and foliation are due to the parallel transmission of planes or waves of heat, awakening the molecular forces and determining their direction,' a view differing from that of Dr. Darwin only in that it assigns the part of pressure to heat. A similar idea with respect to cleavage had been expressed by Sir John Herschel.[1]

X. *The Relation of Cleavage to Earth-movements.*

The theories discussed in the foregoing pages make the cleavage of rocks a result of lateral thrust operating throughout larger or smaller tracts of country, and the extreme stages of the structure, which involve mineralogical as well as lithological changes, a consequence of the intense stresses in the earth's crust[2] to which mountain-systems owe their structure. Into the ultimate cause of these mechanical forces we are not called upon to enter;[3] but some of the resulting peculiarities in the arrangement of cleavage planes over an extended area require a passing notice.

As regards the strike of cleavage, its regularity over considerable distances[4] and its parallelism to the main axes of disturbance of the district in which it occurs, need not be further dilated upon; local exceptions to the latter rule have been noticed by various observers. As regards the cleavage-dip, no such simple laws can be laid down. The angle of dip may have any value, though the most perfect cleavage is usually inclined at a high angle. So far as observation at any one locality can discover, the dip of the cleavage is quite independent of that of the bedding. On traversing a district of slate-rocks in the direction across the cleavage the dip is observed to change very slowly and gradually; when an abrupt variation is noticed there is reason to suspect some disturbance posterior to the production of the cleavage-structure.[5] In fact, subsequent tilting and faulting of the rocks may affect not only the dip but to some extent also the direction of strike of the planes of cleavage; and wherever in the preceding pages we have referred to the cleavage-strike and cleavage-dip, the *original* strike and dip of the cleavage-planes ought strictly to be understood. As another possible source of error in observing the dip of cleavage-planes must be noticed the not infrequent surface-curvature[6] of those planes in consequence of movements of the rocks near the surface of the ground, a phenomenon well seen in the valleys about Snowdon.

Dr. Charles Darwin,[7] who made careful observations of cleavage and foliation over a large part of the South American coast, suggested as an explanation of the varying and opposite dips that the cleavage-surfaces—though to the eye appearing plane—may possibly be 'parts of large abrupt curves with their summits cut off and worn down.' Mr. Sharpe,[8] following out this line, endeavoured to trace out 'systems of cleavage' in

[1] Lyell's *Student's Elements of Geology*, p. 592, 2nd ed.

[2] *Rindenzusammenschub* (Heim), *Gebirgsdruck* (Lehmann), *Pression orogénétique* (Barrois), &c.

[3] For a discussion of this subject, see the concluding part of Heim's *Mechanismus der Gebirgsbildung*, 1878, Basel.

[4] Sedgwick, Jukes, Darwin, Phillips, &c., *op. cit.*

[5] Cf. Jukes, *Manual of Geology*, p. 271, ed. 1862.

[6] De la Beche, *Geological Manual*, p. 42. Darwin, *Geol. Obs. in South America*, p. 160 (1846). Jukes, *Student's Manual of Geology*.

[7] *Geol. Obs. in South America*, p. 146 (1846); 2nd ed. (1876), p. 446.

[8] *Quart. Journ. Geol. Soc.*, vol. iii. p. 74 (1847).

Wales, Cornwall, and Devon, and the Cumbrian Mountains,[1] and subsequently in the Scottish Highlands.[2] He maintained that in each of the districts, which he regarded as distinct areas, there are certain lines of strike, many miles apart, along which the cleavage is vertical; that on each side of such a line the cleavage dips towards it, and at continually lower angles, until midway between two such lines is a zone of horizontal cleavage; so that over such an intermediate place the cleavage-surfaces, if carried on continuously, would pass in broad flat arches. With such an arrangement, low angles of cleavage-dip would be much more prevalent than they are found to be. Professor Phillips criticised Mr. Sharpe's theory and some of the sections on which it was based, and even these sections themselves only bear out the author's view in a very limited degree. It is curious, too, that M. Laugel[3] employed Mr. Sharpe's data to verify his own quite different theory of a sheaf-like or fan-like arrangement of the cleavage-planes of a district, which is much more in agreement with recorded observations. According to Mr. Sharpe[4] this appearance is due to the junction of two of his arches, but certainly the prevailing high dips in most districts where cleavage is well developed point to the fan-like arrangement as the essential part of the phenomena. This latter peculiarity is specially characteristic of mountain systems, where, as noted by Dr. Darwin,[5] the cleavage-planes on the flanks of the mountains 'frequently dip at a high angle inwards.' In a symmetrical mountain complex also there is usually a parallelism between the cleavage-planes and the axial planes of the folds into which the strata are thrown, as remarked by Professor H. D. Rogers.[6] In less disturbed districts the fan arrangement is less perfect, and any connection between the direction of the cleavage-planes and the position of the folds of the rocks is, as a rule, not to be made out except occasionally on a small scale.[7] A traverse through the slate-districts of North Wales seems to show that the cleavage-planes, as it were, oscillate from one side of the vertical to the other when followed in a direction perpendicular to their strike, as if there were a series of imperfect fans; some of the Geological Survey's sections show the same character.

Mr. Sharpe's presumed arch-arrangement was used by him to support an *elevation theory* of cleavage, which was briefly that a mass of fluid igneous matter, forced upward through a fissure coinciding in direction with the axis of the 'area of elevation,' had compressed the surrounding rocks; the pressure being supposed to act radially, the resulting cleavage-planes, which are at right angles to the direction of pressure, would form a flat arch. The fan-arrangement, on the other hand, seems to connect itself in a simple manner with the *lateral compression theory*;[8] for a mountain mass thus elevated would be acted on by lateral thrust somewhat like that in an arch of brickwork; the cleavage-planes, being perpendicular to the thrust at each point, would be arranged like the planes which separate successive bricks in the arch, i.e. in a radiating or fan-like manner.

[1] *Quart. Journ. Geol. Soc.*, vol. v. p. 112 (1849).
[2] 'On the Arrangement of the Foliation and Cleavage of the Rocks of the North of Scotland,' *Phil. Trans.*, 1852, p. 445.
[3] 'Du clivage des roches,' *Bull. Soc. Géol. Fran.*, sér. 2, t. xii. p. 363 (1855).
[4] *Phil. Trans.*, 1852, pp. 447, 448, &c.
[5] *Geol. Obs. in South America*, p. 164 (1846).
[6] *Trans. Roy. Soc. Edinb.*, vol. xxi. p. 447 (1856).
[7] See, *e.g.*, Dr. Sorby's Ilfracombe section, *loc. cit.*
[8] Cf. Pilar, *Grundzüge der Abyssodynamik*, 1881.

The last point we have to refer to is one of some importance, as raising a possible objection to the mechanical theory of cleavage: it is the relation in point of time between the earth-movements and the production of the cleavage-structure. It has been pointed out by Professor Sedgwick,[1] Professor Phillips,[2] Mr. Sharpe,[3] and others, that the cleavage appears to have been impressed on the rocks subsequently to their being thrown into synclinal and anticlinal folds by the disturbing forces. Mr. Fisher,[4] insisting on this view, maintains that 'cleavage is due to an internal movement of the rocks rendered necessary by the disturbed region being left, after elevation, in a position too lofty for equilibrium.' This theory, it will be noticed, ascribes the elevation of the area in question to forces acting directly from below upwards. I have endeavoured elsewhere [5] to show that the kind of movement advocated by Mr. Fisher would result in an arrangement of the cleavage-planes and a difference in the perfection of the structure in different parts of the area, which is quite out of accordance with the facts.

It is evident that the cleavage-planes would be affected by so much of the disturbance of the rocks as was subsequent to their formation, and consequently the cleavage-structure, at least in its final state, must have been of later origin than the foldings by which it is not disturbed. Professor Tyndall [6] seems to be of opinion that the production of the cleavage was more or less simultaneous with the disturbance, and consequently has been actually affected in a certain measure by the displacement of the rocks in which it occurs. At least this is apparently implied in his explanation, quoted above, of the deviations experienced by cleavage-planes in traversing alternating strata; this phenomenon admits, however, as we have seen, of a different explanation. It may be remarked too, that the fan-like arrangement which often characterises cleavage-planes in a district of disturbed strata might be connected with a certain amount of elevation in the central parts of the area subsequently to the setting up of the cleavage structure. But this does not in any way touch the fact that in any ordinary slate district the planes of cleavage may be seen ranging with approximate parallelism through contorted beds, the irregularities of which do not in any way affect the former. From this we cannot but infer that the impression of the cleavage structure on the rocks is an event of later date, in the main, than the tilting and flexures observable in them.

Granting this, however, we are still able to regard the cleavage and the folding as concomitant, though not simultaneous, effects of the same lateral pressure. As has been remarked by Mr. Fisher himself, they are two distinct ways of satisfying the same lateral compression of an area. But as the cleavage involves a rearrangement of the intimate parts of the rocks and an actual compression of their bulk, we might naturally expect it to be a later result of the lateral pressure than those changes which merely consist in displacement of the rock-masses as a whole. This consideration may fairly be held to remove the difficulty alluded to in accepting the theory which refers the origin of cleavage to the same mechanical stresses that brought about the disturbed position of the strata.

[1] *Geol. Trans.*, 2nd ser. vol. iii. p. 474 (1835).
[2] *Brit. Assoc. Rep.*, 1843, Trans. Sect., p. 60; 1856, p. 373.
[3] *Quart. Journ. Geol. Soc.*, vol. iii. p. 104 (1847).
[4] *Geol Mag.*, 1884, pp. 397, 275, 276. [5] *Ibid.*, 1885, p. 15. [6] *Loc. cit. sup.*

On the Strength of Telegraph Poles.

By W. H. PREECE, *F.R.S., M.Inst.C.E.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

THE resistance of timber to rupture has frequently been experimentally investigated both at home and abroad, but almost invariably with the view of determining the dimensions or scantling of beams, trusses, and framed structures. Few experiments have been made upon naturally grown trees with a view of utilising them in their native condition.

Fincham's [1] experiments on the relative qualities of timber used for the masts of ships were made upon cut pieces, 4 feet in length, and 3 square inches in sectional area. The strength of square balks was investigated by Messrs. Tredgold, Barlow, and others, the results giving a constant of 1,341 for red pine in the formula

$$w = \mathrm{K}\,\frac{bd^2}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $w =$ breaking weight in lbs. at end of beam.
$b =$ breadth in inches
$d =$ depth ,,
$l =$ length ,,
$\mathrm{K} =$ a constant dependent on the character of the timber.

The formula for round timber based on the same value of the constant K becomes

$$w = \mathrm{K}\,\frac{4{\cdot}7r^3}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

r being the radius.

The value of the constant quoted above was obtained by experiments on small sections of timber one and two inches square only. Wisely distrusting results obtained in this manner, Mr. Edwin Clark, during the construction of the Britannia tubular bridge, caused trials to be made with beams of red pine 12 inches square, which gave a constant of 810 only, whilst experiments on balks of Baltic fir made by the Mersey Dock Board gave results varying between 771 and 873. Mr. Gavey, during certain investigations made in Bristol in 1876, obtained a constant of 804 from square sections cut out of Norway round telegraph poles.

Telegraph poles in England now consist principally of native grown unhewn Norwegian or Swedish red fir preserved with creosote.

They have acquired their pre-eminence by a species of natural selection, after extended trials of cut Memel timber, native grown larch, and preserved Scotch fir. The Scandinavian red fir is now almost exclusively employed. It seems to have been provided by nature specially for telegraphic purposes.

[1] *Papers on Naval Architecture*, vol. i. pp. 53–4.

The specifications for telegraph poles, in addition to quoting dimensions, prescribe that they are to be winter felled, sound and hard grown (*i.e.*, well-hearted, with the annual rings closely pitched), straight, free from large or dead knots and other defects, to have the bark completely removed, and to contain the natural butt of the tree. They are usually from 5 to 6 inches in diameter at the top, and they grow with a taper that accords satisfactorily with the theoretical law that should give the greatest strength at each section of their length.

No systematic inquiry has, as far as I am aware, been made into the mechanical properties of Scandinavian red fir in its native or unhewn state, though at different times isolated experiments have been made on its resistance to flexure.

The immense growth of the telegraph system in this country, the increased utilisation of public highways with their bends and curves, the wind pressures arising from the rapid multiplication of wires, have forced closer attention to the stresses applied, and to the more scientific bearing of the question. The selection of the proper scantling has been very much a rule of thumb process, but stability has been obtained by struts, stays, and double poles framed together. Subsequent experiments have, however, shown that practical experience has not erred in specifying dimensions.

As considerable doubt existed as to whether constants obtained from square timber could be accurately applied in calculating the strength of naturally grown trees, in which the annual rings of growth were unsevered, it was determined by the Post Office authorities to make careful and accurate measurements of the strength of the poles actually used, and a substantial testing apparatus was constructed for the purpose. A stout wrought-iron cylinder, 14 inches in diameter and 6 feet long, was rigidly held down on a suitable framing by two 2-inch tie rods. The butt of the pole to be tested was placed inside this cylinder to a depth of 5 feet 6 inches, carefully packed all round, and tightly rammed with gravel to represent the conditions when in use. It was then placed horizontally, a scale pan was suspended from what would be the resultant point of a line of wires at the further end of the pole, and weights were added until the pole broke. An oak plank or saddle distributed the load as would be the case on an actual line of telegraph.

Table No. I. contains the results of the experiments made upon ten comparatively newly creosoted poles.

This gives a mean constant with formula 2 of 1,337, that obtained from the seven stout poles alone being 1,302, and from the three light poles 1,417.

As the investigation referred primarily to lines built with stout poles, 1,302 is the value used in calculating subsequent tables.

Table No. II. contains the results of similar experiments made upon six old poles creosoted fifteen years ago, and upon three uncreosoted poles imported in 1884, the constants being 1,276 and 1,232 respectively.

As previously stated, formula 2 is really derived from experiments made on square timber, a multiplier being used to reduce results when round timber is in question. But obviously the strength of round timber varies as the cube of the diameter, so a constant has been obtained for the formula

$$w = K \frac{D^3}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

D being the diameter;
whilst for poles of elliptical section it becomes

$$w = K \frac{D^2 \times D_1}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

D being the axis in the line of stress, and D_1 that at right angles to it.

The value of K, for formulæ 3 and 4, as deduced from the mean of the experiments on new stout creosoted poles, is 765.

It appears from these experiments that creosoting does not impair the strength of red fir, and age has had no apparent influence on its qualities.

The curves formed by the poles in bending were very perfect. Rupture invariably took place at the ground line, and about half broke by fracture of the upper fibres under tension, while the other half buckled in the under fibres under compression, showing that nature had proportioned them well to their work.

An important question that arises out of this inquiry is what shall be the proper scantling of timber and the span separating the poles on telegraph lines of varying number of wires.

In solving this problem we have not only to take into consideration the proper factor of safety to be allowed, and the wind pressure to be exerted upon the wires and the poles, but the fact that the diminution of spans beyond certain limits is impracticable owing to the injurious lowering of the insulation by the multiplication of supports.

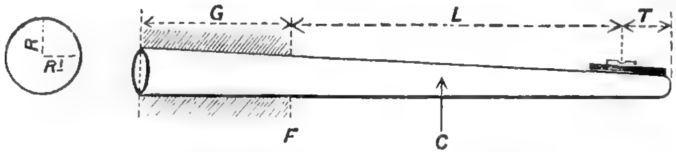
The factor of safety is 4, and the maximum wind pressure per square foot is taken at 18·75 lbs., reducing the effective area in the ratio of ten to six, owing to the circular section of the wires. We know very little of the average pressure on a long wire supported close to the ground. Most records have been made in exposed positions, and at considerable heights, whereas the average height of a trunk line of wires is but 20 feet above the surface. The President of this Section (Mr. Baker) thinks 30 lbs. per square foot a fair average to take for telegraph wires when very much exposed, but considering the frictional resistance of the ground and the obstructions due to hedges, banks, walls, trees, &c., I am inclined to consider this too high for low levels. We have usually taken 18·75 lb. per square foot as a fair measure of the wind pressure on our wires, and the results of practice very much confirm this view.

Table No. III. has been drawn up showing the strength of round poles one foot long, and varying in diameter from 6 to $13\frac{3}{4}$ inches. To obtain the strength of any pole it is only necessary to divide the tabulated breaking strain by the length of the pole in feet.

The strength of the timber being satisfactorily settled, and a maximum wind pressure and factor of safety having been accepted, the length of spans for varying lines is readily calculated. Tables IV. and V. give the stresses on seventeen and twenty wire lines, so arranged as to fulfil the implied conditions.

The experiments and calculations in this paper were done by Mr. Andrew Bell and Mr. John Gavey, of the Post Office Telegraph Department.

TABLE I.—*Tests of Ten Creosoted Poles (a to k) and of a Red Deal Scantling (l), made at Gloucester Road Factory (January 1885).*



DETAILS OF L AND T.

M = cubic contents: feet.

C = distance of centre of gravity from F.

w = weight in lbs.

DETAILS OF LOAD.

$$w^1 = \frac{W \times C}{L}.$$

$$w^2 = \begin{cases} \text{Jockey} & . \quad 9 \\ \text{Saddle tree} & \quad 84 \\ \text{Scale} & . \quad 165 \\ \text{Chain} & . \quad 35 \end{cases} = 293.$$

w^3 = Added load.

VALUE OF K.

$$\text{For poles} = \frac{W \,.\, L}{4{\cdot}7 \,.\, (R^2 \times R^1)}.$$

$$\text{For scantling} = \frac{W\,L}{D^2\,B}.$$

Pole: Index	Pole: Length ft.	Pole: Length in.	Pole: Class	Pole: Weight per cubic ft. in lbs.	G	L	T	Section at F: R	Section at F: R¹	L + T: M	L + T: C	L + T: w	Weight in lbs.: w¹	Weight in lbs.: w²	Weight in lbs.: w³	W	Value of K in formula $W = K\frac{4{\cdot}7 r^3}{l}$. Results in lbs.	Mean value of K in formula, $W = K\frac{d^3}{l}$ for stout poles in lbs.	Relative area of Section F	Relative value of K	When Creosoted
	ft.	in.			in.	in.	in.			c. ft.	in.	lbs.									
a	26	3	stout	41·9	60	214	41	4·1	3·9	6·02	110	252	129	293	1,431	1,853	1,286·88		5	3	Early in 1881 (¹)
b	26	2	,,	37·3	60·5	212	41·5	4·2	4·15	6·31	109	235·4	121	293	1,723	2,137	1,316·672		6	5	,, ,, (²)
c	28	4	,,	49·0	67	239	41	4·6	4·55	7·99	116	391·5	190	293	2,019	2,502	1,321·488		9	7	,, 1882 (³)
d	30	0½	,,	51·0	60	252	41	4·45	4·4	7·97	122·5	406·5	197	293	1,656	2,146	1,320·48		8	6	Dec. 1884 (⁴)
e	34	5	,,	44·1	66	306	41	5·0	4·75	11·13	136·5	490·8	219	293	1,797	2,309	1,265·823	765·2512	10	2	May 1882 (⁵)
f	24	1	light	50·7	54·5	193	41·5	3·55	3·45	4·09	96	207·3	103	293	1,175	1,571	1,483·776		1	10	Sept. 1884 (⁶)
g	26	0	,,	49·7	60	209	41	3·7	3·6	4·8	108	238·5	123	293	1,212	1,628	1,468·880		2	9	,, 1883 (⁷)
h	28	1	,,	47·3	60·5	235	41·5	3·95	3·75	5·46	110·5	258·2	121	293	1,107	1,521	1,299·766		3	4	April 1882 (⁸)
i	29	10½	stout	45·2	64·5	252	41·5	4·05	3·95	7·69	142	347·5	196	293	949	1,438	1,190		4	1	,, 1884 (⁹)
k	33	8	,,	39·5	66	298	40	4·5	4·2	8·78	143	346·8	166	293	1,442	1,901	1,417·136		7	8	1870 or 1873 (¹⁰)
								D	B												
l	13	11½	—	32·3	36	89	42·5	5·5	4·0	1·67	65·75	54·2	40	120	789	949	698·0176		—	—	— (¹¹)

Average value of K in tests *a, b, c, d, e, i, k*, for formula $W = K\,4{\cdot}7\,\frac{R^3}{l} = 1{,}302{\cdot}56$ lbs.

,, ,, ,, $W = K\,\frac{D^3}{l} = 765{\cdot}2512$ lbs.

Quality of Timber and Remarks.—(¹) Very hard grown; (²) medium grown; (³) medium grown, sapwood large, fracture flaky; (⁴) very hard grown; (⁵) medium hard grown; (⁶) medium hard grown; (⁷) medium hard grown; (⁸) very hard grown; (⁹) very hard grown; (¹⁰) very hard grown, fracture flaky; (¹¹) rather a coarse piece, placed in error heart side up, fracture at a knot just inside F. (*Note.*—Some of the poles fractured by elongation of the upper fibres, some by compression or buckling of the lower ones.)

TABLE II.—*Further Pole Tests made at Gloucester Road Factory (in April and May* 1885), *viz. six indexed l, m, n, o, p, and q, creosoted and erected in* 1870 *or* 1871, *and three uncreosoted indexed r, s, and t, imported in* 1884.

Pole: Index	Pole: Length (ft.)	Pole: Length (in.)	Pole: Class	Pole: Weight per cubic foot (lbs.)	G (in.)	L (in.)	T (in.)	Section at F: R (in.)	Section at F: R^1 (in.)	L + T: M (c. ft.)	L + T: C (in.)	L + T: w (lbs.)	Weight in lbs.: w^1	Weight in lbs.: w^2	Weight in lbs.: w^3	W	K for result in lbs.	Relative area of Section at F	Relative value of K	When creosoted	Bending a permanent set: Load = lbs.	Deflection at top end, ins.	Recovery when load removed
l	28	0	medium	40·22	64	231	41	4	3·6	5·81	120	234	121	293	1,342	1,756	1,497·44	1	8	1870 or 1871	1,414	32	recovered [12]
m	26	0	stout	42·46	66	204·5	41·5	4·75	4·25	6·56	98	279	133	293	1,674	2,100	952·8736	8	1	,,	1,776	27	,, [13]
n	26	0	,,	36·85	65	205·5	41·5	4·4	4·1	5·55	95	204	95	293	1,530	1,918	1,056·5072	6	3	,,	1,250	23½	,, [14]
o	27	11	medium	40·45	64·5	229	41·5	4	4	6·53	121	264	139	293	1,518	1,950	1,484·448	3	7	,,	1,355	29	,, [15]
p	26	0	stout	40·93	64·5	206	41·5	4·3	4	5·72	103·5	234	117	293	1,339	1,749	1,036·4816	4	2	,,	1,480	27	,, [16]
																					1,700	28	,, [17]
q	26	0	,,	43·11	65·5	205	41·5	4	3·7	5·49	109·5	237	126	293	1,789	2,208	1,626·8	2	9	,,	1,969	35	recovered all but 1½ in.
																					1,629	35½	recovered [18]
r	29	7	,,	35·27	66·5	247	41·5	4·8	4·6	8·03	113	285	130	293	1,794	2,217	1,099·3136	9	4	uncreosoted	1,855	43½	recovered all but 2 in.
s	30	0	,,	34·06	66	252·5	41·5	4·5	4·25	7·72	122	263	127	293	1,602	2,022	1,262·128	7	5	,,	1,668	36½	recovered [19]
																					1,280	31	,, [20]
t	29	10½	,,	39·97	66	251	41·5	4·3	4·25	7·58	124	303	149	293	1,520	1,962	1,333·360	5	6	,,	1,429	48	recovered all but 3½ in. [21]

Note.—For explanation of the headings see Table of Tests *a* to *k*, made at Gloucester Road Factory in January 1885, Table I.
Note.—Poles indexed . . . . . *l* to *q* are believed to have been erected in 1871 or 1872.
,, ,, ... *m, n, p, q* were taken down in March 1882.
,, ,, ... *l* and *o* were taken down in August 1883.

Quality of Timber and Remarks.—([12]) Hard grown, very sound, fracture 2 ft. from **F**; ([13]) sound timber, still smells strongly of creosote, fracture short 17 in. from **F**; ([14]) medium quality, fracture by compression 3 in. from **F**; ([15]) soft grown, fracture by compression 18 in. from **F**; ([16]) knotty and soft grown, fracture 3 ft. from **F**; ([17]) hard grown and tough, fracture by compression 18 in. from **F**; ([18]) soft, fracture by compression 18 in. from **F**; ([19]) sound hard wood, fracture 31½ in. from **F**; ([20]) no note, fracture 2 ft. from **F**; second, fracture 6 ft. from **F**.

TABLE III.—*The Calculated Strength of Round Poles one foot long.*

Diameter meters	Breaking weight in lbs.	Diameter meters	Breaking weight in lbs.
6	13,776	10	63,773
6·25	15,568	10·25	68,678
6·5	17,517	10·5	73,819
6·75	19,611	10·75	79,218
7	21,873	11	84,874
7·25	24,304	11·25	90,798
7·5	26,902	11·5	96,992
7·75	29,725	11·75	103,454
8	32,648	12	110,196
8·25	35,807	12·25	117,219
8·5	39,166	12·5	124,555
8·75	42,716	12·75	132,182
9	46,491	13	140,100
9·25	50,467	13·25	148,344
9·5	54,678	13·5	156,901
9·75	59,102	13·75	165,782

To obtain the strength of any pole divide the tabulated breaking weight by the length of the pole in feet between the ground line and the resultant point of the load.

TABLE IV.—*Wind Pressure,* 18·75 *per sq. ft.—factor of safety of* 4; *Strains and Strength of* 17 *wire line*; 60 *yards spans; calculated to constants obtained at Gloucester Road.*

Length of Pole	No. 8 Wire		No. 14 Copper		Present specification diameter
	Moment of Pressure in lbs.	Safe diameter	Moment of Pressure in lbs.	Safe diameter	
26	8,344·0	8·25	3,953·6	6·0	8·25
28	9,374·4	8·5	4,446·4	6·5	8·75
30	9,811·2	8·5	4,648·0	6·75	9·0
32	10,796·8	8·75	5,118·4	7·0	9·25
34	11,771·2	9·25	5,577·6	7·25	9·75
36	12,264·0	9·25	5,790·4	7·5	10·0
40	14,224·0	9·75	6,742·4	7·5	10·75

TABLE V.—*Wind Pressure,* 18·75 *per sq. ft.—Strains and Strength of* 20 *wire line:* 60 *yards span: calculated on constants obtained at Gloucester Road.*

Length of Pole	No. 8 Wire		No. 14 Copper		Specification diameter
	Moment of Pressure in lbs.	Safe diameter	Moment of Pressure in lbs.	Safe diameter	
26	9,811·2	8·5	3,953·6	7·5	8·25
28	10,964·8	9·0	5,196·8	8·0	8·75
30	11,547·2	9·0	5,465·6	8·0	9·0
32	12,700·8	9·25	6,014·4	8·5	9·25
34	13,854·4	9·5	6,563·2	8·5	9·75
36	15,545·6	10·0	7,369·6	9·0	10·0
40	16,732·8	10·25	7,907·2	9·5	10·75

On the Use of Index Numbers in the Investigation of Trade Statistics. *By* Stephen Bourne, *F.S.S.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

Whatever opinions may be held on the oft-mooted question whether statistics are to be deemed a science or merely as an art, there can be no denying that statistical research may, and ought to be conducted on scientific principles. The collation of facts, the method in which they are grouped and treated, and the results attained by such treatment, is as truly the pursuit of science as is the study of many another branch of knowledge directed to the discovery and promulgation of truth. Many of the elements with which statisticians have to deal are obscure and variable, but the conclusions they may be made to support are capable of being of as definite establishment as those worked out by the processes of the more exact sciences. One of the methods resorted to is the use of an 'index number,' which as its name denotes, indicates certain conditions and connections of figures which it is otherwise difficult to associate with each other. The use of this method is not without difficulty, and two or three instances in which it has been adopted may serve to illustrate both its merits and its disadvantages, as well as an introduction to the special occasion for its application which forms the subject of this paper.

The late Professor Jevons, in a pamphlet on the fall in the value of gold published in 1863, sought in this manner to indicate the various changes which had taken place in the price of the various articles of commerce following upon the then recent gold discoveries in Australia, and from thence to infer that the altered nominal values were in reality due to a depreciation in the value of the precious metal in which these prices were expressed. Later on, the same evidence of a fall in price was adduced in proof of the subsequent appreciation of gold, which more recently both Mr. Goschen and Mr. Giffen have asserted to be still in progress. Collecting together the average mean prices of thirty-nine different commodities during the six years of 1845–50, the Professor took these as the *datum* line with which to compare those of the three years 1860–2. Subsequently adding to these seventy-nine new commodities, and by logarithmetic calculations dividing the arithmetical averages of the former period into that of the later three years, he obtained a ratio or percentage which represented the rise of prices presumed to be due to the fall of gold. Having thus reduced prices expressed in various coins—pence, shillings, and pounds—and appertaining to quantities denoted by various weights, measures, and numbers, to a series of index numbers each having a definite and proper relation to the commodity it represented, it became possible to add together the equivalents of that which could not be otherwise combined, and so to obtain an average marking a distinct alteration with respect to gold. This was taken to establish a universal rise in price corresponding to a depreciation of gold by about 9 per cent., which was thereby deemed to be proved to have taken place.

The 'Economist,' commencing with the average price for the same six years, 1845–50, of each of twenty-two separate articles or groups of

articles, to which it gave the index number of 100, has year by year calculated for a new index number the percentage of variation in price and thus indicated the specific yearly rise or fall down to the present time. Thus cotton wool, the price of which was represented at the commencement of the series by 100, the actual price being $8\frac{1}{4}d.$ per lb., rising to $10\frac{3}{8}d.$ in 1873, was represented by 126, the result of $\frac{10\frac{3}{8}\times 100}{8\frac{1}{4}}$. In the interval it had risen in 1866 to the equivalent of 267, and in 1883 fell so low as 71. It is evident that $\frac{126+267+71}{3}=154\frac{2}{3}$, or leaving out from each the original 100, $\frac{26+167-29}{3}=54\frac{2}{3}$ would give the index numbers for the average price or increase of price for those three years, and by conversion back into pence show the actual price and increased price: for as $100 : 154\frac{2}{3} :: 8\frac{1}{4} : 12\frac{3}{4}$ and $100 : 54\cdot\dot{6} :: 8\cdot25 : 4\cdot51$, and so on for every succeeding year. Each of the twenty-two articles being on the datum line as 100, the total index number becomes 2,200, and the several new numbers in the following years being added together, we get 3,564 and 2,947 as the totals for 1866 and 1873, with 1,364 and 747 as the respective indications of the general rise in prices. The index for 1st January, 1885, is but 2,098, showing, so far as this table is evidence, that we have now reached the lowest prices for at least thirty-five years.

This table however—good as it is so far as it goes—is defective, inasmuch as it only deals with the quotations for forty-four distinct articles out of the numerous commodities in which we deal, and it takes no account of the relative importance of the articles, either in the range of value, or the quantities bought and sold. Thus wheat at 30*s.* to 50*s.* per quarter, of which we grow some 80,000,000 bushels, and import some 120,000,000 more, reckons for no more than indigo at 2*s.* to 8*s.* per lb., the transactions in which must be limited to the 100,000 cwts. we import. Again, including as it does four descriptions of cotton, each numbering as one out of twenty-two, the unusual fluctuations to which this article is subject affects the index number, for the years in which this may occur, in a fourfold degree. The same to less extent may be said of iron. These sources of derangement, together with that of the entire omission of such an important article as coal, led me, in a paper on the silver question read before the Statistical Society in 1879,[1] to substitute corrected index numbers in which these two sources of error were avoided. The effect of these corrections was to reduce amongst others the average index number of 1865 from 162 to 138, and to increase that of 1873 from 134 to 142. It is obvious also, as the 'Economist' itself remarks, 'that in the course of so long a period of years, 1845–84, some variations have inevitably arisen in the mode of quoting prices.'

It must be evident therefore that imperfections in the data upon which these calculations are made prevent entire confidence in their results, notwithstanding the scientific accuracy in the methods employed. It is probable, however, that for the purpose of comparing one year with another or others, especially with those not separated by long intervals, the ratio of progress is accurate. In such statistics as these, which embrace a multitude of small items, and thus afford opportunities for minor errors to balance each other, the results are not far from the truth, even

[1] 'Some Phases of the Silver Question.' *Stat. Journal*, vol. xliii.

though the figures for one or other period may not be absolutely correct. Since each one is liable to the same chances of error, the relative accuracy may thus be quite sufficient for purposes of comparison.

The most recent instance of the use of index numbers is perhaps that contained in this year's report upon 'Changes in Imports and Exports,' rendered by Mr. Robert Giffen to the Secretary for the Board of Trade. The object here sought for is to ascertain the yearly progress of the nation's trade with colonies and countries outside its own borders, both as regards its money value and the volume of the goods which it receives and parts with. This, so far as the value is concerned, is easily ascertained by the figures published year by year in the 'Statistical Abstract,' which sets forth the value of each principal article of both import and export, with the combined value of all the minor articles, and then collects them all into one total which shows in one sum the aggregate import, and in another, that of export. Thus we find without any calculation that in 1883, the last year with which the paper deals, the imports were valued at 427,000,000*l.*, whereas ten years ago they were at 371,000,000*l.*, showing an increase of 56,000,000*l.* Also that the values of the exports at the same dates were 240,000,000*l.* and 255,000,000*l.*, the difference being 15,000,000*l.* against the later period. In like manner that the sum total at one time was 667,000,000*l.*, and at the other 626,000,000*l.* Also that the imports exceeded the exports in 1883 by 187,000,000*l.*, and in 1873 by 116,000,000*l.* These particulars are by no means all that are needed for the formation of a true judgment as to our trading prosperity or adversity. To the banker or the broker it may be sufficient to know the gross amount on which commissions may have been earned or charges realised; but the merchant needs to understand the changes in the goods which have passed through his hands, the shipowner has to take note of the quantity of goods he has carried. So the economist looks to be informed of the volume of our trade, and it is the business of the statistician to evolve from such data as are within his reach the fullest information they are capable of furnishing. This is not so easy as at first sight it appears to be.

The 'Statistical Abstract,' the only source of information dealt with on the present occasion, sets forth the principal articles in quantity where that is capable of expression, and the respective values for each enumerated article, all others being included in one total of value only. If the investigation be confined to one article alone, little more than inspection is needed. Take for instance pig iron, of which we exported in 1883, 1,564,000 tons, at a value of 4,077,000*l.*, and in 1873, 1,142,000 tons, at 7,118,000*l.*; and cotton yarn 265,000,000 lbs., at 13,500,000*l.* in the one year, and 215,000,000 lbs., at 15,895,000*l.* in the other. There is no difficulty in seeing wherein the quantities and values have in each case changed, but inasmuch as the quantity of one is stated in tons and the other in pounds weight, and the unit values are in pounds and in pence, we cannot as with the money add the two together, to see whether on the whole the bulk has increased and in what proportion. Much less could all the goods having the quantities in yards, gallons, &c., be thus brought into one representative sum. Mr. Giffen therefore takes 100 as the index number for the total value, say of exports in 1883, which we have seen to be 240,000,000*l.* Then to find the proportion of the pig iron value, says, as 240,000,000 : 4,077,000 :: 100 : 1·7, the index number for pig iron; and as 240,000,000 : 13,500,000 :: 100 : 5·6, the

index number for cotton yarn. Pursuing the same course with each of the other articles of export for that year, which are enumerated in quantity as well as value, and adding them all together, he arrives at a total of 61 as the index number of the whole, which stands as the index number or representative of 146,000,000*l.* out of 240,000,000*l.* In like manner dealing with any other year, say 1873, he takes 100 to represent its total value of 255,000,000*l.*, and finds the index number of the enumerated articles to be 67·2. It should be observed here that the index number for 1883 is $\frac{61}{100}$ of 240,000,000*l.*, and that for 1873, $\frac{67\cdot2}{100}$ of 255,000,000*l.*, so that the two index numbers do not stand in a definite relation to each other. This is a defect, as I venture to think it, to which allusion will be made further on. Thus far the process has been with values only, and the index numbers show no more than the actual money figures do. The use to be made of them is to get other index numbers that shall represent quantities also, and so determine whether, and to what extent, the volume as well as the value of one year has changed with reference to the other. This is effected by the following means. In the first place, a simple division of the total value by the total quantity of each article in each year will show the average price per unit whether that be a ton, pound, yard, gallon, or any other measure.

Keeping for illustration to the two articles already quoted, it appears that $\frac{4,077,456l.}{1,564,048\text{ tons}}$ gives 52·14*s.* as the price per ton of pig iron in 1883, and $\frac{7,118,037l.}{1,142,065} = 124\cdot65s.$ the price for 1873, giving a decrease of 72·51*s.*, which shows that this article was more costly by 139 per cent. in the earlier than the later year. So with cotton yarns $\frac{13,509,732l.}{264,772,000} = 12\cdot25d.$, and $\frac{15,895,440l.}{214,778,827} = 17\cdot76d.$, from whence it is seen that this article was 45 per cent. higher in price in 1873 than in 1883. If now, we increase the index numbers of 1883 by 139 and 45 per cent. respectively, we get $\frac{1\cdot7 \times 139}{100} = 2\cdot36$, and $\frac{5\cdot6 \times 45}{100} = 2\cdot52$ as additions which will represent the alterations necessary when quantity is considered as well as value.

Mr. Giffen, however, has preferred a comparison with 1861, and to take the proportion of each article as it was in 1875 instead of that of each year, and has worked out the alterations thus to be made for twenty of the years included in the period 1840–1873. Taking then the total index number ascertained for 1875 to be 65·8, he finds that 1873 is + 19·93, whilst 1883 is − 5·95; that is (though he does not so state it), these changes would make that for 1883, compared with 1873, as 59·85 to 85·73, in which proportion the values of the latter year must be increased to bring them into comparison with the former. Thus 146,000,000*l.* must be increased to 209,000,000*l.*; and assuming that the non-enumerated articles vary in the same ratio $224,000,000l. \times \frac{85\cdot73}{59\cdot88} = 321,000,000l.$, as the value to which the total exports of 1883 would have reached had the prices been the same as in 1873.

Adhering to the principle of the foregoing calculations, there would

yet appear to be room for simplifying and improving upon them. In the first place it seems erroneous for the purpose of comparing one year with another or others, that the component parts from which the yearly index numbers are built up, or rather we should say into which each of them is split up, should not have a common basis to rest upon, so that they may be added to or subtracted from each other, and then converted back into the figures of actual values, as for instance, cotton yarn in 1865 is 6·2 per cent. of 166,000,000*l.*, in 1883 5·6 of 240,000,000*l.*, and therefore cannot be combined without previous reduction to a common denominator. It is proposed therefore to reduce all to one standard, and to choose 240 millions, the total exports of 1883, for the datum amount. This too because in the latter year a greater number of articles are specifically enumerated, and we can in consequence operate upon a larger proportion of the whole. It is evident that whether we take 1, 10, 100, or 1,000 as the standard index, the figures into which it is divided will be the same, only differing in the place of the decimal point. In the Board of Trade tables 100 is chosen, which for closeness of calculation requires the use of decimals, and also of the plus and minus signs, whereas if 1,000 be taken we avoid the use of both, and all our indices are in whole numbers. Thus the total value of enumerated articles in the tables, which is expressed by 61·0, or by adding 9·4 for articles not included in the enumeration of earlier years, will appear as 704, which is the same thing without the point. But that for 1840 will be 214 instead of 79·1. Hence $\frac{704}{1000}$ and $\frac{214}{1000}$ can be added together or otherwise dealt with, because the denominator signifies the same amount, but $\frac{70{\cdot}4}{100}$ and $\frac{79{\cdot}1}{100}$ cannot be, because the 100 stands in one case for 240 and in the other for 51 millions. The one set of tables will show at a glance the proportion which exists between every figure they contain, which the other requires an elaborate calculation to discover.

The object to be attained, as already pointed out, is to get a number which shall indicate for each article, and for the whole together, the bulk as well as the value, and so to ascertain the very important point, whether the changes, both in the respective items and the grand total, are due wholly, or in what proportion, to an increased or diminished volume of goods, or to a variation in the prices at which they are valued. Hence it is convenient to make 1883 the year for comparison, rather than 1861, which Mr. Giffen uses, and this once established may be utilised for succeeding years, until some great alteration in the conditions of trade may make it necessary to adopt some new method of exhibiting its effects.

The number of distinct articles which are specified, both as to value and quantity, is 65, for each of which individual calculation has to be made in each year. These furnish a wide enough range for assuming with safety that those which cannot, for want of definite information as to quantities, be so estimated, may be taken in the same ratio of bulk as the others are found to yield. The mode of estimation is first to convert the value for each given year into a number proportionate to that of 1,000, which is the index number for 1883. Then taking the price per unit, be it a pound, a gallon, or a yard, as deduced from the amounts and shown in the 'Statistical Abstract,' to consider that for 1883 as 1·00, and for other years in the percentage of increase or decrease. Having thus obtained a divider for the value index, the resulting number becomes

an index of quantity for each article, and so by simple addition for the whole of the specified articles in each year. To illustrate this process, in 1883 the exports of cotton yarn were in round numbers 265,000,000 lbs., and the value 13,500,000*l*., in 1865 they were 103,500,000 lbs. weight, and 10,300,000*l*.; the price per lb. being 12·25*d*. and 23·98*d*. respectively, or 96 per cent. higher in the earlier year. The value index of 56 stands for 1883, but being multiplied by 1·96 we change it into 110 to represent the value 26,400,000*l*. which would have accrued had the price been the same as in 1865. Or reversing the process we divide 42, the index for 1865, by 1·96, giving 21·5, to show the value 5,165,000*l*. which the yarn of that year would have realised had it been sold in 1883, and thus get the ratio of quantity to value for this article. All the enumerated goods being dealt with in the same way, and the non-enumerated assumed to follow the same ratio, it is evident that the index numbers fairly indicate the proportionate bulk of the trade in the respective years. The following tables in which the enumerated articles, instead of being separately detailed, are gathered into groups, show first (A) certain index numbers for 1883, and the changes which would have to be made on estimating the goods at the prices of three other years within the decade 1873–83, and of one earlier year 1865, in which the disturbance of prices arising from the American Civil War exercised a marked influence upon the export trade of this country. Secondly (B), the index numbers for these same four years are shown in parallel columns with the alterations that the prices of 1883 would have produced. These illustrate the manner in which the full set of tables for a series of years may be easily used to manifest the fluctuations in quantity as well as value, either by way of comparison between later and earlier or earlier and later years.

A.—*Exports of* 1883 *in Index Numbers, together with those numbers as they would have been at the prices of other years.* 1,000 = 240,000,000*l*.

Articles Grouped	1883	Additions to 1883 for Prices of			
		1879	1875	1873	1865
Cottons	299	12	68	100	243
Linen and Jute	36	1	5	8	13
Woollens	89	−6	19	23	27
Chief Textiles	424	7	92	131	283
Coals	44	−3	20	54	1
Iron	118	−1	59	109	36
Other Metals	21	−1	7	9	4
Chief Minerals	183	−5	86	172	41
Other enumerated	99	2	17	23	26
All other goods	294	2	82	137	147
Total Exports	1,000	6	277	463	497

Exports of 1883

At prices of 1883	Index No. 1,000	= 240,000,000*l.* value
„ 1879	„ 1,006	= 242,000,000*l.*
„ 1875	„ 1,277	= 306,000,000*l.*
„ 1873	„ 1,463	= 351,000,000*l.*
„ 1865	„ 1,497	= 359,000,000*l.*
„ 1884	„ 1,010	= 243,000,000*l.*

B.—*Exports of five different years in Index Numbers, with those numbers as they would have been if changed into prices of* 1883.

The Black Figures at 1883 prices.

	1883	1879		1875		1873		1865	
Cottons	299	255	**245**	287	**234**	312	**233**	238	**131**
Linen and Jute . .	36	33	**32**	43	**38**	44	**36**	49	**36**
Woollens	89	80	**86**	110	**[illegible]1**	123	**98**	107	**82**
Chief Textiles .	424	368	**363**	440	**363**	479	**367**	394	**249**
Coals	44	30	**32**	40	**28**	55	**25**	19	**18**
Iron	118	81	**81**	107	**76**	161	**84**	64	**49**
Other Metals . . .	21	18	**19**	20	**15**	22	**15**	17	**14**
Chief Minerals .	183	129	**132**	167	**119**	238	**124**	100	**81**
Other enumerated . .	99	79	**77**	86	**73**	90	**73**	58	**46**
All other goods . .	294	222	**221**	238	**202**	256	**175**	140	**94**
Total exports . .	1,000	798	**798**	931	**739**	1,063	**727**	692	**460**

	Actual values. Index No.	£		At prices of 1883. Index No.	£
1883 .	1,000	= 240,000,000	.	**1,000**	240,000,000
1879 .	798	= 192,000,000	.	**798**	192,000,000
1875 .	931	= 223,000,000	.	**739**	177,000,000
1873 .	1,063	= 255,000,000	.	**727**	174,000,000
1865 .	692	= 166,000,000	.	**460**	111,000,000
1884 .	970	= 233,000,000	.	**1,010**	243,000,000

The index number of 1,000 that has been employed to represent the 240,000,000*l.* of British produce and manufactures exported in 1883, and to which all the other numbers have the same relation, might have been applied to the value of 1884, and would have been so done but that the 'Statistical Abstract' for last year was not published in time. The figures required could be gathered from other sources, but not in quite the arrangement of their component parts which fits them for the comparison that will be made when the 'Abstract' makes its appearance.[1] So large an index number has been used for convenience in calculating the very numerous items depending upon it, but it is obvious that by cutting off the three ciphers and prefixing or inserting the decimal point in other places, we shall have the relation of all the other figures to the value of

[1] *Vide* end of paper, pp. 872–3.

1883 as the unit. We have then for the last twelve years, 1884–73, the following actual values and their respective index numbers:—

	£	Index No.
1884	232,927,575	·971
1883	239,799,473	1·000
1882	241,467,162	1·006
1881	234,022,678	·975
1880	223,060,446	·929
1879	191,531,758	·798
1878	192,848,914	·803
1877	198,893,065	·829
1876	200,639,204	·835
1875	223,465,963	·931
1874	239,558,121	·998
1873	255,164,603	1·063
Average	222,781,583	·928

Stating also the values of 1865 and 1864 we get a comparison with two years of high prices though not of large exports. In

1865	£165,835,725	Index No. ·692
1864	£160,449,053	„ ·669

But this Index may also stand for the collected quantities of the goods exported in 1883, and then represents the x or unknown gallons, yards, cwts., &c. of the various articles, whether detailed or not in the trade figures; and as already shown it may be split up into its component parts. Altering each one of these according to the variation of the prices of other years and collecting them into one total, we get a comparison between the bulk which the index of money in the standard one 1883 bears to that of other years, for it needs no explanation to show that a given amount of money represents a greater or lesser quantity of goods according as the prices of these were lesser or greater. Thus (A) taking the index number of 1883, as standing for both money and quantity, and altering it for each of the four years given by way of illustration in the foregoing table, we get a number which enables us to estimate the growth in bulk at present as compared with the past. Or (B) taking the index number for each of those years as standing for quantity and money alike, and altering it to the standard of prices in 1883, we ascertain what proportion quantities in those years bear to the later one.

A. At prices of former years	1883 Index No. 1·	B. At prices of 1883. Index No. 1·		
in 1879 would have swollen to	1·006	·798 would have shrunk to	·798	= 1 to 1
1875 „ „	1·277	·931 „ „	·739	= 1 to ·794
1873 „ „	1·463	1·063 „ „	·727	= 1 to ·684
1865 „ „	1·497	·692 „ „	·460	= 1 to ·665.

The one set of figures indicating the enlarged volume of goods the money of 1883 would represent as compared with its predecessors, the other the contracted bulk of those previous years as compared with 1883.

One more comparison is needed to show the full bearing of these numbers. The actual difference betwixt the values of the trade of one or more years and other years is thus compounded of two elements, the one arising from differing quantities, the other from varying prices. The foregoing increases to the index numbers of 1883 do not indicate the additions to the value of our trade, but only what would have resulted

from a maintenance of the prices obtained in former years. They in every case exceed the actual differences between the index numbers, and consequently the money value of the several years, which being deducted from the apparent increase which represents the bulk, the remainder will show the diminution in the value of this branch of our trade in 1883 from that of the other quoted years. This will be made more distinctly apparent by disregarding the use of the index numbers and showing the sums which they represent. In the following table, column (A) is the total value of the exports in the years previously noted; (B) the excess or deficiency of the figures of 1883 over or below those amounts; (C) the additional sums which would have accrued in 1883 had each former year's prices remained; and (D) the consequent net remunerative advantage or disadvantage to our whole export trade in 1883, as compared with the four earlier and one subsequent year, regard being had to both quantity and price.—

	A Million £	B 1883 + or −	C 1883 + or −	D
1883	239·80			
1879	191·53	+ 48·27	− 2·	+ 46·
1875	223·47	+ 16·33	− 66·	− 50·
1873	255·16	− 15·36	− 111·	− 127·
1865	165·84	+ 73·96	− 119·	− 46·
1884 with 83	232·93	− 6·87	+ 10·	+ 3·

Prior to the publication by the Board of Trade in 1879 of its first report, to which that already referred to relating to the trade of 1883 is a successor, the 'Economist' compiled tables arriving at much the same results by an independent method. In these, without resorting to an index number, the value of the goods of the later year was directly calculated at the prices of the former, to show how much the bulk would have realised had there been no change of price, the difference being the gain or loss from having obtained higher or lower prices. Thus the difference between these computed sums and the actual values manifested the gain or loss due to greater or smaller quantities. These tables have been continued from year to year, and being drawn from the figures of the monthly trade account published seven days after the last day of each month, the readers of that paper have before them, within a month after the termination of each year, a pretty accurate comparison with the trade of its predecessor in imports as well as exports. Calculations for exports on the same plan between 1883 and 1873, and dealing with articles represented in the later year by 166,000,000*l.*, showed that the prices of the earlier one would have given 83,000,000*l.* more than they realised, and the actual difference in the values of the two years, 23,000,000*l.*, was thus shown to give 60,000,000*l.* as the loss from diminished value lessened by the increase in volume. The value of the non-enumerated goods being assumed to have followed the same course will give results agreeing with index number method, and so confirm the accuracy of both.

Similar figures, to be found in that paper for 31st January last, are for the present used in the foregoing tables to show that whereas the exports for 1884 were valued at 232,928,000*l.*, as against those of 1883, the gain

from increased sales of 2,733,000*l.* was lessened by 9,604,000*l.* from lower prices, the actual difference adverse to last year being 6,871,898*l.*

Of the present year, only two-thirds having elapsed, it is impossible to speak definitely, but assuming that the next four months will follow the same course as those which are gone, it is probable that there will be a further decay of 21,000,000*l.* on the total of last year. Of this a rough calculation points to one-third as the probable loss from quantity, and two-thirds the failure in prices.

Although the purport of this paper has been to explain the method of investigation rather than the results to be obtained by its use, it would scarcely be right to leave wholly untouched some of the evidence it elicits, or the problems whose existence may thus be manifested, though not solved. Had time permitted, illustrations might have been drawn from the import records which admit of exactly the same treatment that has been bestowed upon the exports. Before this, however, it may be well to allude again to the differences of the two methods as accounting for the figures evolved by the one process differing from those produced by the other.

It has been previously noticed that the selection by Mr. Giffen of 1861 as a basis narrows the list of articles which can be specifically calculated by so many as were not enumerated in that year, and so throws the calculation on the whole year to be made upon a smaller proportion. In 1883, 61· instead of 70·4, leaving 39· to be averaged instead of 29·6. But it does more than this, for many of the classes left out in the later year are really included in the earlier. For instance, the total value of iron exported in 1861 was 10,000,000*l.*, and in 1883, 29,000,000*l.*, but only 6·4 represented the latter, whilst 5·6 stood for the former in building up the index numbers, owing to the exclusion of descriptions separately shown in 1883, but included under more general heads in 1861. This applies still more to earlier years.

Then the choosing for the index number a percentage of the actual value of its own year, instead of some fixed datum, rendered the figures of unequal values in the different years. Thus 61, the index for 1883, meant $\frac{61}{100}$ of 240,000,000 = 146,000,000*l.*, whilst 71·1, for 1861, meant $\frac{71 \cdot 1}{100}$ of 125,000,000 = 89,000,000*l.*, each unit of the index being of double value in one year to what it bore in the other.

Again, taking the proportions of 1875 as those to which the increased prices should be reckoned as affecting the index of all years alike, could only be correct for such years as happened to have the same relative quantities as in that particular year, and must be particularly injurious where a very high or low price happened to be coincident with a greatly varying quantity. This too would be aggravated or minimised by the proportions being those of value rather than of quantity. Thus the proportions of cotton yarn for 1865, 1875, 1883 stood as 104 : 216 : 265, but by value as 10 : 13 : 14, and the percentages of increase or decrease from the standard of 1861 were as + 91·23 : + 41·63 : − 2·31. It is difficult to see how any combination of these factors, so widely differing in their ratios, can bring about the result that the index numbers for cotton yarn should be altered as +5·38 : +1·00 : − 0·14 as shown in the Board of Trade tables.

The effect of these three several arbitrary departures, as they seem to

be, from sound bases in the Board of Trade tables does not affect the total results so much as might be supposed, from the fact that the year 1875 on which the calculations are made was one unmarked by any great irregularity in any of the articles, either in quantity or price, and also from the deviations happening to take different directions, so as to neutralise each other. The effect of the two systems may be shown side by side for the five years already detailed in a previous table, where the alteration in the index numbers, and the export values they represent, were based upon the prices of 1883, thus:

	Prices of 1883			Prices of 1861	
	Actual Values	Index No.	Altered Value	Index No.	Altered Value
	£		£		£
1883	240,000,000	1,000	240,000,000	59·85	264,000,000
1879	192,000,000	798	192,000,000	59·70	212,000,000
1875	224,000,000	739	177,000,000	74·47	198,000,000
1873	255,000,000	727	174,000,000	85·73	196,000'000
1865	166,000,000	460	111,000,000	89·26	122,000,000

The prices of 1861 having been 10 per cent. higher than those of 1883 would make that difference between the calculated values in each of the years. These index numbers of 1861 will not however permit of being added together, either in the whole or the several parts, for the different articles, because they are in each year percentages of varying totals, whilst those for 1883 are in every case a percentage of the same amount, namely the total of that year, 240,000,000*l.*

But having got these altered values by applying the prices of one year to others and deducting from them the actual values of the respective years, it would appear in the case of the three years that the bulk of our trade in 1883 is to be measured as more than 1875 by 83,000,000*l.*, than 1873 by 96,000,000*l.*, and than 1865 by 193,000,000*l.* But both 1865 and 1873 are abnormal years in which the extravagant prices of coals, and therefore of iron, or of cotton, ran the total values up to an undue extent, and so by the large proportion they are of our whole trade had an unfair influence, not only upon the values of these goods themselves, but upon the average of the non-enumerated as well. For instance, the price of cotton in 1865 raised the index number in comparison with 1883 by adding 243 to 299, being 81 per cent., whereas all the other enumerated articles together only added 107 to 405, being 24 per cent. In like manner the cost of coals in 1873 added 54 to 44, at the rate of 123 per cent., and the other goods, excepting metals which were almost equally affected, were increased 309 on 521, or but 59 per cent. For the ultra free-trader therefore to compare the results of these two exceptional years, as has often been done, with 1883, is about as absurd as should some opponent of sanitary reform in Spain compare the death-rate of some future year, when cholera has ceased its ravages, in proof of the superior healthiness of the nation in the later over the previous year. The true worth of such investigations is historical, as furnishing one factor amongst the many which are combined in influencing the prosperity of trade, and sets of tables thus constructed may possibly be of great help in the collection of information towards solving the problems committed to the consideration of the recently appointed Royal Commission on Trade.

It is essential that one other warning be given. After all the care which can be exercised in eliminating sources of error, it is not at all certain that the quantities of goods, though expressed in the same denominations, are in truth alike in the substance of the unit. A ton of coals cannot vary in quantity, or greatly in quality, from year to year, but a yard of cotton piece goods may greatly alter in width, thickness, and fineness of texture, according to the make which happens to be saleable at the time. Fabrics of mixed materials, such as cotton or jute conjoined with wool or silk, do greatly change in the proportions of the dearer substance, as well as in size or texture, according to the fashion of the day. There is good reason to believe that in all these respects the yards of both cotton and woollen goods are now intrinsically less valuable than they were in past years, and in whatever degree this may be true of these and other goods, the comparison of goods by the price, weight, or measurement must be fallacious. As an instance of this, it happened that the value given for a consignment of shirtings to New Zealand was challenged as being preposterously low. The production of invoices proved the figures of both yards and money to be absolutely correct, and that the goods were really described as shirtings. But further inquiry elicited the fact that these goods were destined not to make shirts for Europeans, or even for Maories, but to form shrouds for the carcases of sheep in the refrigerating chambers of the vessels bringing them home. For this purpose a much inferior article was serviceable, although in the trade accounts it would necessarily be grouped with those of far higher quality and price.

But it is high time to leave these wearisome details and descriptions, and to point out a few of the purposes for which the tables may serve. They must be regarded as means, not ends; tools wherewith crude and unsightly statistics may be reduced into useful, and it may be comely shapes. Like interest tables and logarithmic numbers, though equally tedious to construct, and far more difficult to describe, they may save a vast amount of labour to those by whom they are used, and lead up to results of real utility.

In the first place, the extreme variation of price within short periods of time, and the equal irregularity of their recurrence, forbid the assumption that gold is now or has very lately been altering in value. I do not say that it may not have become appreciated, but if so the evidence to sustain the theory must be sought elsewhere. When coals rose from 8·84*s.* in 1863 to 20·49*s.* in 1873, and in 1883 sank to 9·20*s.* it cannot be affirmed that the change was in the metal rather than the mineral. Contrast this with cotton yarn, which in the three years named stood at 26·01*d.*, 17·76*d.*, and 12·25*d.* Like the gold itself, to procure which we must crush down the quartz in which it lies imbedded or wash away the sand with which it is mixed before the grains are discovered, so the hard mass of statistics, or the encumbering multitude of figures, must be ground or boiled down if we would eliminate the truth from the surrounding sources of error so prone to lead the judgment astray.

In the next place, by bringing out so clearly the great accessions to the bulk of our trade, and yet limiting these changes within narrower bounds than many economists are disposed to admit, we discover the severe fall which prices have sustained, and hence the enormous quantity of goods we have to give for an equal or lesser amount of money. Comparing 1883 with 1873, for instance, we find the actual value of the goods we sold to have been 15,000,000*l.* less, or a fall of 6 per cent., whereas

the goods given were at least 40 per cent. more. It is often claimed that this is but a temporary alteration, accompanied by conditions which neutralise the injury. No doubt in many cases there has been a contraction in the cost of the materials employed which, if imported from abroad, especially from foreign countries rather than our colonies, is a clear saving to the nation. Yet even this is not so when home capital is employed in their production abroad. But when, as with coals and iron, the whole proceeds of the sale are distributed at home, the diminution of these proceeds is a home loss. Improved mechanism or increased industry may have lessened the expenditure on production by diminishing or restraining from proportionate increase the numbers to be sustained out of these proceeds; and to this may be attributed the number of workers who are out of employ, or what is still more largely the case at present, the short time in which they are working. But it surely cannot be gravely maintained that there is here no depreciation in our most important means of obtaining wealth. Neither does an attentive consideration of these figures afford any assuring indication that the evil is in process of passing away. Again, we find that the decay in prices of imports is greatly below that of exports. Even Mr. Giffen's figures show that the index number by which the bulk of the trade is estimated—for the exports of 1865 has to be altered from 65·8 by the addition of 23·46, and for 1883 by the deduction of 5·95, a correction of 45 per cent., whilst that of imports has to be changed from 81·16 by an addition of 13·59 and deduction of 9·43, a correction of but 28 per cent.—the corresponding alteration in total value having been 47 and 36 respectively; that is, we have lost nearly twice as much by the reduced prices of our sales as we have gained by those of our purchases. It seems mockery to talk of enlarged trade as a proof of national prosperity when these are the terms on which it is conducted. But in truth the whole of this part of the question depends upon whether the prevailing lowness of prices is due to causes which are removable or temporary, or to such as are in process of increase and so likely to be enduring.

It is by no means to be presumed from what has been said that the consideration of these figures or the grave teachings they afford are in any way calculated to support a return to protection, or whatever is meant by 'fair' as opposed to free trade. The declension in prices and the consequent destruction of profits arise from the fierce competition to which our manufactures are exposed in the markets of the world, and especially in those countries which wield protection against us. These evils would be multiplied tenfold by any steps which would increase the cost of our home products for foreign sale. It is to the extension of the ground our markets cover, and to increased economy of production, that both manufacturer and artisan should look for the desired recovery from the prevailing depreciation of their products.

I fear that details and figures such as these have been difficult to follow without diagrams large enough to be seen, but trust that those who are accustomed to follow calculations of this sort will not think I have altogether failed in the attempt to put them upon a truly scientific basis.

The following table shows the method of arriving at the index numbers and of comparing one year with another. The index number for the

price of each article in 1883 is 1 or 100, according to the use or otherwise of the decimal point. The index for quantity is the same as that for value in the standard year (1883); that for 1884 is arrived at by dividing the value index by the price index, and is shown in the last column. The variations in prices between these two years are not sufficient to alter many of the smaller index numbers unless carried to one or two decimals. It will be seen, however, how few are the articles of which the quantity is large enough to have much influence upon the total result.

British Goods exported in 1884, *compared with those of* 1883.

1883				1884				
Articles	Aver. Price	Value of Exports: In million £'s	Value of Exports: Index No.	Aver. Price	Value of Exports	Index Numbers: Value	Index Numbers: Price	Index Numbers: Quantity
Alkali ....cwt.	6·12*s.*	£2·12.	9	6·37*s.*	£2·09.	9	1·04	9
Anls., horses ......ea.	55·62*l.*	·41.	2	58·36*l.*	41.	2	1·05	2
Arms, fire .... ,,	27·40*s.*	·36.	1	25·68*s.*	39.	2	·94	2
Gunpowder......... lb.	5·83*d.*	·38.	2	5·82*d.*	39.	2	1·00	2
Bags ....doz.	5·16*s.*	1·14.	5	4·88*s.*	1·01.	4	·95	4
Beer ....brl.	79·82*s.*	1·82.	8	75·11*s.*	1·64.	7	·94	7
Books ....cwt.	9·55*l.*	1·17.	5	9·43*l.*	1·17.	5	·99	5
Butter .... ,,	139·58*s.*	·21.	1	140·18*s.*	·20.	1	1·00	1
Candles ......doz. lbs	6·72*s.*	·15.	1	6·66*s.*	·21.	1	·99	1
Cement ....cwt.	2·31*s.*	·93.	4	2·25*s.*	·87.	4	·97	4
Cheese .... ,,	84·15*s.*	·06.	—	84·08*s.*	·06.	—	1·00	—
Coals ....ton	9·35*s.*	10·65.	44	9·29*s.*	10·85.	45	·99	46
Cordage............cwt.	51·05*s.*	44.	2	45·53*s.*	·42.	2	·89	2
Cotton yarn.........lb.	12·25*d.*	13·51.	56	12·24*d.*	13·81.	58	1·00	58
,, manfd.								
plain ...yd.	2·61*d.*	34·15.	142	2·47*d.*	31·85.	132	·95	140
printed ,,	3·62*d.*	20·83.	87	3·60*d.*	19·81.	83	·99	84
mixed ,,	5·81*d.*	·55.	2	7·53*d.*	—	—	1·29	—
,, stockings doz.	3·28*s.*	·54.	2	6·25*s.*	57.	2	1·00	2
,, thread ......lb.	3·27*s.*	2·36.	10	3·37*s.*	2·48.	10	1·03	10
Fish, herrings ...brl.	29·73*s.*	1·43.	6	24·75*s.*	1·65.	7	·83	8
Glass, plate ...sq. ft.	1·42*s.*	·26.	1	1·45*s.*	·27.	1	1·02	1
,, flint.........cwt.	44·94*s.*	·34.	1	46·94*s.*	·30.	1	1·05	1
,, common... ,,	9·27*s.*	·36.	2	9·30*s.*	·35.	1	1·00	1
Hats ....doz.	21·50*s.*	1·14.	5	21·43*s.*	1·15.	5	1·00	5
Leather ....cwt.	9·34*l.*	1·64.	7	9·45*l.*	1·68.	7	1·01	7
,, boots dz. prs.	60·10*s.*	1·54.	6	59·92*s.*	1·58.	7	1·00	7
Jute yarn............lb.	3·05*d.*	·27.	1	2·79*d.*	·32.	1	·91	1
,, manfs. ......yd.	2·64*d.*	2·50.	10	2·43*d.*	2·46.	10	·92	11
Linen yarn ....lb.	14·36*d.*	1·06.	4	13·95*d.*	1·14.	5	·97	5
,, manfs.								
white ......yd.	6·95*d.*	4·41.	18	6·62*d.*	3·96.	17	·95	18
printed ... ,,	7·80*d.*	·21.	1	6·47*d.*	·19.	1	·83	2
sail cloth ,,	11·73*d.*	·17.	1	10·95*d.*	·21.	1	·93	1
,, thread ....lb.	2·61*s.*	·29.	1	2·43*s.*	·31.	1	·93	1
Iron, old............ ton	3·47*l.*	·34.	1	3·28*l.*	·22.	1	·94	1
,, pig............ ,,	52·14*s.*	4·08.	17	46·40*s.*	2·95.	12	·89	14
,, bar............ ,,	7·06*l.*	2·03.	8	6·55*l.*	1·94.	8	·93	9
,, railroad...... ,,	6·19*l.*	6·01.	25	5·69*l.*	4·14.	17	·92	19
,, wire .... ,,	14·80*l.*	·93.	4	13·08*l.*	·69.	3	·88	4
,, sheet......... ,,	10·12*l.*	1·48.	6	9·38*l.*	1·35.	6	·93	7
,, galvanised ,,	15·18*l.*	1·75.	7	14·30*l.*	1·74.	7	·94	8

British Goods—cont.

Articles	1883 Aver. Price	1883 Value of Exports In million £'s	1883 Value of Exports Index No.	1884 Aver. Price	1884 Value of Exports	Index Numbers Value	Index Numbers Price	Index Numbers Quantity
Iron, hoop ....ton	7·77*l.*	·67.	3	7·27*l.*	·60.	2	·94	2
„ tinned ...... „	17·47*l.*	4·71.	20	16·45*l.*	4·75.	20	·94	21
„ cast .... „	12·97*l.*	4·62.	19	12·17*l.*	4·58.	19	·94	20
„ steel, wrght. „	19·10*l.*	1·40.	6	19·80*l.*	1·13.	5	1·04	5
„ „ mfs. „	42·70*l.*	·58.	2	36·37*l.*	·40.	2	·85	2
Copper ingots ...cwt.	3·38*l.*	1·14.	5	2·94*l.*	1·05.	4	·87	5
„ yellow metal... „	2·99*l.*	1·18.	5	2·73*l.*	1·06.	4	·91	4
„ other kinds „	3·87*l.*	1·24.	5	3·52*l.*	1·46.	6	·91	7
Brass .... „	4·47*l.*	·43.	2	4·24*l.*	·45.	2	·95	2
Lead ....ton	14·07*l.*	·55.	2	12·58*l.*	·42.	2	·90	2
Tin..................cwt.	4·88*l.*	·52.	2	4·27*l.*	·47.	2	·87	2
Zinc .... „	13·89*s.*	·10.	—	13·59*s.*	·10.	—	·98	—
Oil-seed............gal.	1·85*s.*	1·86.	8	1·83*s.*	1·47.	6	·99	6
Paper..............cwt.	2·15*l.*	1·28.	5	2·05*l.*	1·37.	6	·95	6
Salt ....ton	12·84*s.*	·65.	3	12·91*s.*	·61.	3	1·01	3
Silk, Brd. stfs. ...yd.	3·26*s.*	1·25.	5	3·26*s.*	1·11.	5	1·00	5
Soap ....cwt.	22·96*s.*	·45.	2	22·99*s.*	·55.	2	1·00	2
Spirits..............gal.	5·93*s.*	·81.	3	6·15*s.*	·81.	3	1·04	3
Sugar..............cwt.	21·40*s.*	1·24.	5	17·77*s.*	1·11.	5	·81	6
Wool..................lb.	12·71*d.*	1·03.	4	10·94*d.*	·83.	3	·86	3
„ yarn........... „	23·41*d.*	3·27.	14	23·78*d.*	3·89.	16	1·02	16
„ cloth ....yd.	38·30*d.*	7·35.	31	41·42*d.*	7·93.	33	1·08	31
„ flannels ...... „	14·82*d.*	·84.	3	13·98*d.*	·91.	4	·94	4
„ stuff .... „	9·94*d.*	7·69.	32	9·64*d.*	8·72.	36	·97	38
„ carpets ...... „	28·24*d.*	1·26.	5	26·16*d.*	1·26.	5	·93	6
Total specified articles	—	170·14.	706	—	163·87.	683	—	711
Total unenumerated do.	—	69·66.	294	—	69·13.	288	—	299
		£239·80.	1·000	—	233·00.	971	—	1·010

The Forth Bridge Works. *By* ANDREW S. BIGGART, *C.E.*

[PLATE VI.]

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

WORKS of exceptional magnitude, and more especially those in which the difficulties in the way of their accomplishment are in any degree proportionate to their size, must of necessity be of interest to this Association, constituted as it is to assist, and in its own way act as a beacon to all in search of true knowledge.

While the difficulties met with in preparing for and founding the piers

of the Forth Bridge have been neither few nor unimportant, it is patent, to even the uninitiated, that causes for anxiety will neither disappear nor diminish till the erection of the steel superstructure has been completed.

Presently my remarks will be confined to the main steel piers and approach viaducts. The term steel piers refers to those parts of the superstructure immediately over and between any of the three groups of four caissons. Described generally, each may be said to consist of two sloping and two vertical planes; the sloping, including one connecting horizontal column and two 12-foot rising columns, joined at the upper extremities by the top member, while from the lower end of each to the top of the opposite one there extends a diagonal eight-foot tube. These two planes run parallel with the centre line of the bridge, and are 120 feet apart at the base and 33 feet at the top.

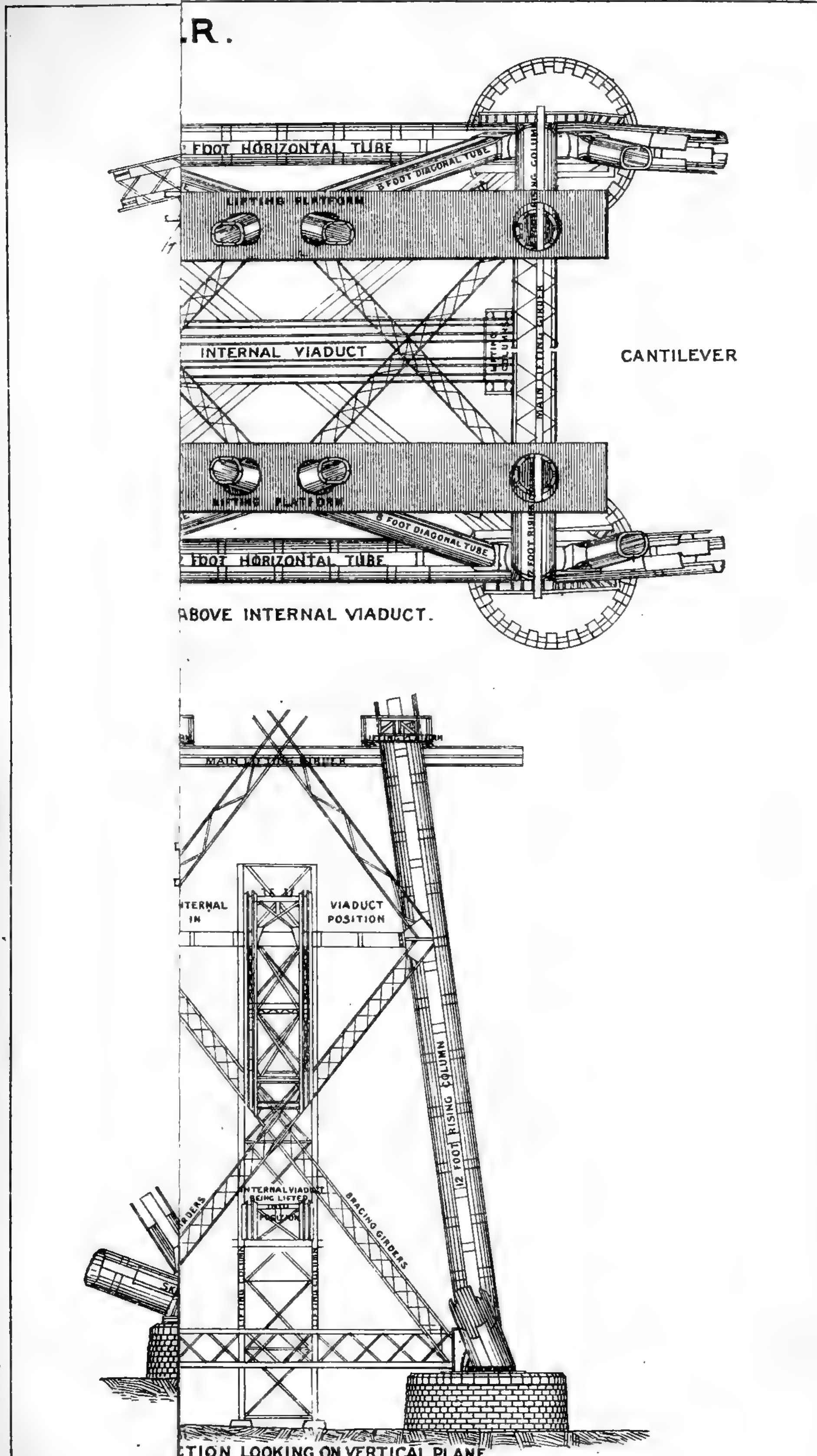
The vertical planes complete the structure at the ends of the two sloping planes. They consist of the 12-foot rising columns, already mentioned, with the lattice bracing joining these together. These members, with the internal viaduct and the bracing girders attached to the skewbacks, form the principal parts of the steel piers, the extreme height of which is fully 340 feet above the bottom of the lower bedplates.

The approach viaducts are, generally speaking, of ordinary design, with the exception of some special features to meet the unusual requirements demanded of them. The girders span a distance of 160 feet, and rest on granite-faced piers, rising to a height of 130 feet above high water; the heights of these piers themselves gradually diminishing as they near the abutments, owing to the rising nature of the banks of the river.

The magnitude of the main steel piers, both in respect of their great height and immense weight, demands that exceptional means be employed in their erection. Many proposals for effecting this have been suggested, and may be said to range from that of Mr. Arrol's first, which was to run up the columns independently, using them as the only staging, to that proposed by Mr. Baker, viz., to carry up simultaneously with the columns a rising platform, extending round the whole four columns, by utilising them as supports, and upon this platform to carry up the top member, having the end junctions all previously riveted up, so that on arrival at the top the final closing lengths of the 12-foot rising columns had only to be joined to the junctions already fitted, to complete this part of the work. After careful consideration the weight requiring to be lifted was found to be too great, when compared with the advantages to be gained, to allow of its full adoption In the case of the Fife and Queensferry piers, the weight was close on 1,200 tons, and several hundred tons more in that of Inch Garvie.

A modification of this plan is that finally adopted by Mr. Arrol, with Sir John Fowler and Mr. Baker's full approval. The carrying up of the top member is done away with, but otherwise it is very similar.

The main lifting girders of the platform pass through the 12-foot rising columns, and running in line with the vertical planes extend from the one sloping plane to the other. Lying across these are placed other four girders, one being on either side of each set of 12-foot rising columns, thus completing a rectangular platform resting indirectly on the main rising columns. The weight of this platform, including the necessary cranes and other plant required during the erection of the higher parts of the pier, will be about 400 tons.



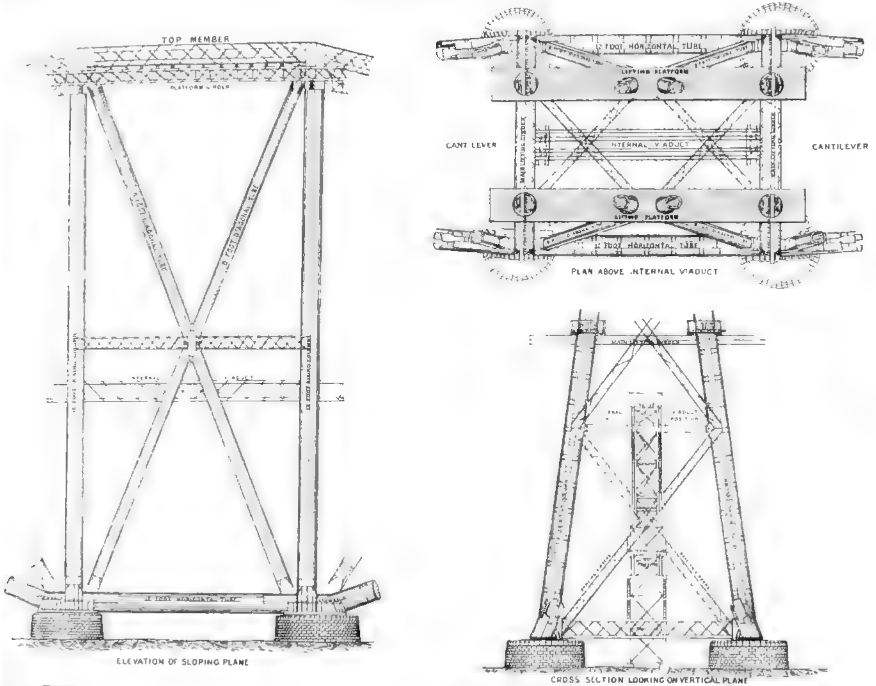
ABOVE INTERNAL VIADUCT.

CTION LOOKING ON VERTICAL PLANE.

Spottiswoode & Co. Li

e Works.

FORTH BRIDGE FIFE MAIN STEEL PIER.



Illustrating Mr Andrew S. Biggart's Paper on The Forth Bridge Works.

The first part of the superstructure is that termed the lower bedplate. Several of these are now completed and in position. They are made up of a series of longitudinal and transverse plates, securely riveted together, and run about 37 feet long by 17′-8″ wide, with a thickness of from 3 to 4 inches. The whole plate is bolted on a number of short iron columns *in situ*, and is riveted up by a special hydraulic machine. Two girders are employed, one above and the other below the bedplate; and extending beyond it are there joined together. On each of these girders slides a hydraulic cylinder, one having a little more effective area than the other, while both are regulated by the same cock. The result is that when water is admitted the total pressure on one cylinder is greater than that on the other, thereby holding the rivet-head firmly in place while the point is being pressed up. The work thus produced is of the very highest quality; since the whole machine moves lengthwise, and the cylinders slide crosswise, the full surface of the plate is commanded by it. The riveting is also done expeditiously, the machine being capable, in ordinary work, of closing during a single shift 600 $1\frac{1}{8}''$ countersunk rivets. When finished, the bedplate is finally lowered into position.

The upper bedplate or base, on which the various connections at the foot of the rising column rest (and which collectively constitute what is termed the skewback), is proposed to be riveted in a like manner to the lower bedplate. While being riveted it will be secured to heavy steel girders instead of columns, as in the case of the lower bedplate, to keep it in true form. After lowering the upper bedplate into position, the diaphragms and various other parts will then be built on it, and riveted up by common hydraulic machines as well as by the special hydraulic machines designed by Mr. Arrol for the purpose. As many of the spaces in which riveting has to be done are very confined and difficult of access, high pressures will be used with machines correspondingly small. Thus while the ordinary pressure will still be 1,000 lbs. per square inch, it will be increased in some cases to as high as 3 tons per square inch, by a simple pressure multiplier, wrought by the ordinary 1,000 lbs. pressure. This low pressure is admitted to the large end of the compressing ram, the smaller end of which produces the increased pressure (proportional to the difference in areas) required to close up the rivet properly.

The riveting machine is very small, each cylinder weighing about half a hundredweight. The smallest proposed cylinder is only 4 inches diameter, is of the simplest form, and contains a hollow plunger provided with a single cup leather at the inner end. A spring is secured to the plunger and back end of the cylinder, for the purpose of drawing back the plunger, when the exhaust water is allowed to escape. When in place and at work the machine will be hung to the one end of a small wire, passing over a pulley, while at the other will be fixed a balance weight to relieve the operator of the weight of the machine. Two cylinders, one outside and one inside, will be required at the closing up of the rivets. Both will be connected to the compressor and wrought by it.

The horizontal tubes, skewbacks, and lower parts of all the columns will be built by ordinary cranes till they attain a height of about 30 feet above the bedplates. At this point of the 12-foot rising columns will then be commenced the longitudinal channels (through which are drilled the holes for the steel pins to pass through them and the cross girders); to these channels the cross girders will now be attached within the column, on the higher of which will be laid the two main lifting girders of the

platform. Extending between and beyond these, but at right angles, will be the other girders required to complete the rectangular platform already referred to. The principal work above this will be executed from this platform as it is being raised towards the top of the pier. In that work will be included the 12-foot rising or supporting columns, the eight-foot diagonal columns, and the bracing in the sloping planes. The vertical planes will be built similarly as the platform is raised upwards. When all is ready to be raised for the first time, the positions of the various members in the pier will be somewhat as follows. The four rising 12-foot columns will have the whole of their channels and eight of the ten plates in section, in each column, at a convenient working height above the platform. The other two plates require to be kept off at this point, to allow the main lifting girders to pass through the columns, and can only be placed in final position from underneath the main lifting girders. The columns will only be bolted together at this point, but as few more bolts will be required than those necessary to make good work when riveting up, very little labour will be lost. The eight-foot diagonal tubes in the sloping planes will also be carried up above the level of the platform. They pass between the girders, and lie in the sloping planes, and will be wholly riveted up above the level of the platform. The bracing in the vertical planes, being 12 feet wide, allows the main lifting girders to pass through it, and will be built to a large extent from a platform on the top of these girders, only the top and bottom bracing requiring to be placed and riveted in position underneath the main lifting girders, while the whole of the tubes will be built in single pieces. In the case of the bracing girders it is intended to take up and fix in position sections of a size convenient for handling with despatch under the somewhat novel circumstances around.

The riveting machines employed will be of various forms, the common type being used for such work as the bracing girders, while those for the rising and horizontal columns will be the same in principle as those riveters employed for the bedplates, with several special features to suit the different kind of work. The girders on which the cylinders slide will be similar, and similarly placed in relation to the work to be done, one being outside the column and the other inside, while at the ends they are secured to and made to slide round two circular rings by a small hydraulic cylinder. Stiffening packings or struts are placed between these circular rings and the channels of the columns inside and plates outside, to keep all in true form, and these are transferred from one point to another as the girders pass the various positions at which they are placed.

The girders are thus made to move round the complete circle, and as the hydraulic cylinders on these slide a length of 16 feet, it follows that the riveting done at each shifting of the machine is equal to this length of the completed column. To enable the riveting to be executed with the longitudinal built up channels complete, the power of the hydraulic cylinder on the inner girder is transmitted to the rivet through a lever of the third order, this cylinder having the amount of greater area necessary to exert nearly the same pressure as the cylinder on the outer girder. It is proposed that the whole machine be fixed to the platform and underneath it. It will consequently be raised with it, but during the stationary periods between the lifts, it will rivet up the 12-foot rising columns close to but always underneath the main lifting girders. Each machine is made to carry its own working platform, from which all the necessary operations will be conducted.

The raising of the main platform by the hydraulic cylinders placed within the 12-foot rising columns will be performed thus. Water will first be admitted to the lower end of two of the hydraulic cylinders in one or other of the sloping planes, sufficient to ease the main lifting girders and the two upper cross girders within the columns. The pins through these cross girders and the channels of the columns being withdrawn, water is again admitted and made to raise the one end of both main lifting girders one foot; when this is accomplished the same pins are reinserted, and the load again transferred to the cross girders. The water in the lower end of the cylinders now being allowed to escape, that in the small annular space at the other end, and which is constantly acting as a back pressure, raises the cylinders and with them the lower cross girders to the same position relative to the upper girders which they occupied before the lifting operations began. As the pin holes in the four lifting channels run the full height, the point to which the platform may be lifted at any one shift is a matter of expediency. This lift in most cases will be about 16 feet, but in any case it will be effected by single lifts of one foot at a time, as already described.

It will be apparent that the manner of lifting at the different points in each platform is exactly similar. The cylinders being in line with the 12-foot rising columns and made to raise the platform to all intents vertically, induces a slight rocking motion, which is provided for in the cylinders by planing their bottom surfaces to a very obtuse angle, the apex of which is slightly rounded off to form a better bearing.

As the platform is raised the girders in line with the sloping planes will be slid towards the centre of the bridge, each pair on either side being always kept as near as practicable at an equal distance from the centre of the rising columns.

The raising and riveting will thus be carried on till the whole arrives at the top of the pier, the platform being then in a convenient position on which to build the top members extending between the columns in line with the bridge. These will now be built, and with them the top junctions or connecting portions of the upper part of the steel pier, resembling in many respects the lower junctions termed the skewbacks. All will be riveted in position by the machines already referred to.

After the main platform has passed the point at which the internal viaduct is joined to and made to form an integral portion of the bracing in the vertical plane, the lifting of the girders, &c., of which this part is composed (and previously riveted complete) to its position will then be commenced. This will be done by means of four complete sets of columns, girders, and hydraulic cylinders. The cylinders will be placed within and fixed to the upper of two cross girders sliding on and temporarily bolted to the two vertical columns at each corner of the part to be raised. Passing between and extending across from one set of columns to the other will be the carrying girders, resting on the top of the upper cross girders and bearing the portion to be lifted into position. The ram will be made to point downwards and bear against the top of the lower cross girder. When water is admitted to the upper end of the cylinders, the bolts in the higher cross girders meanwhile having been withdrawn, the rams are forced against the lower cross girders, but as these are securely fixed to the columns, the hydraulic cylinders with the cross girders, carrying girders, and structures to be raised are bodily lifted upwards. When raised about one foot the upper cross girders are again fixed to the

columns and made to carry the load. The water is now allowed to escape, and as there is a back pressure in the cylinders similar to that in those used for raising the main platform, the rams are forced into the cylinders, and being secured to the lower cross girders are made to raise these also. This action will be repeated till all is raised to the desired height, when the girders will be quickly secured to the points previously prepared for their junction with the bracing in the vertical planes.

In addition to the several parts of the bridge already mentioned, the cantilevers will form a leading subject for careful thought. The proposed method of their erection is, however, beyond the scope of this paper, and I need only remark that all concerned see their way to successfully overcoming this part of the work also.

The approach viaducts on both sides of the Firth are presently in a forward state of progress; the girders on the south side, immediately over the water, being practically complete, having been built on timber staging, the top of which was on a level with the stone piers, so far as completed, or about 18 feet above high water. These girders will be raised to the level of the next stage erected on shore, on which will have been built during the time occupied in that lifting another pair of girders to which the first portion of the viaduct will be connected. This raising and joining to other portions still higher up will be continued till the full height is reached, when all the ten spans will be complete.

The north viaduct is in a more forward state than the south, it being wholly completed with the exception of a few of the end bays, which cannot be put in position till a higher point has been reached. The whole of the north viaduct piers are on land of a very undulating character. This necessitated some of their number being raised a considerable height so that a uniform level throughout might be attained, and all the girders built at the same time on a stage similar to that used for the other side.

The piers provide points from which the lifting can be easily and safely done. Various proposals for effecting this were discussed; that finally sanctioned by Sir John Fowler and Mr. Baker is to place underneath the end pillars of the main girders on each pier a temporary cross girder extending between and beyond these, and bearing up the whole weight, on timber blocking resting directly on the pier. In each of these temporary cross girders are placed two hydraulic cylinders, one being directly underneath each main girder; in both, the ram faces downwards. Each cylinder is provided with a separate valve to regulate its action in raising. When at rest the temporary cross girders will transmit their load to the piers, either through the blocks placed close to but between the lifting cylinders or those outside and nearer the ends of the piers, this being determined by the point at which building has to be carried on. If in the centre then the supports are outside, and *vice versâ*, the ram when lifting will bear on a prepared sole of hard wood spreading somewhat over the stonework. Great care must be exercised to keep the different bearings in the whole viaduct as near one uniform level as possible during the lifting operations, to avoid any undue straining of the main girders. As soon as the structure has been raised the full stroke of the cylinders, a new lift will be commenced, the blocks on which the rams bear having, however, been previously packed up. The height required to give ample clearance for building underneath will be about four feet.

At the ends of the north viaduct, in lieu of a bearing on the piers,

columns with all the other appliances have been provided, similar to those to be adopted for lifting the internal viaduct already described.

A hoist is provided for lifting from the ground underneath the main girders the whole of the stone, &c., required in building the piers upwards from their present level. This material will be raised while on trollies, and while still on these run along the temporary road laid on the bottom of the main girders to any or all of the piers. On arrival at any pier it can be raised and laid in position by a pair of small runners fixed to the girders immediately above each pier. The power used for raising, lowering, or traversing either way being transmitted through special horizontal winches driven by a rope extending well nigh the full length of the viaduct, the work will thus be carried on till the desired end is attained, that being reached when the rail level is fully 150 feet above high water.

Were I to state that these are the exact methods by which those parts of the bridge presently treated of will be erected, I should only be laying myself open to the ridicule of all experienced engineers, as it is a well-known fact that no undertaking of such magnitude is ever carried out to the letter of the plans originally decided upon. The foregoing are only presented as the results arrived at after full discussion by all concerned, and as the principles on which the full details will be wrought out as the work proceeds. Thus far all has gone well, no difficulty having arisen which can be said to have taxed the latent ability of either the engineers or contractors; and judging the future from the past there is every reason to conclude that in the near future the successful erection and completion of the Forth Bridge will be a matter of history.

Electric Lighting at the Forth Bridge Works.

By JAMES N. SHOOLBRED, *B.A., M.Inst.C.E.*

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

IN the summer of 1883 the contractors for this most important engineering work, Sir Thomas S. Tancred, Arrol, & Co., decided to make use of electricity in the illumination of the works required for the preparation and construction of this large undertaking. The author was by them entrusted with the preparation of the necessary plans, together with the supervision of the arrangements to enable the lighting by electricity to be thoroughly and suitably carried out.

For the construction of the bridge and the proper preparation of the large amount of steel which enters into it, very large workshops have been erected at South Queensferry, where also are concentrated the principal offices, central stores, canteen, &c. A steep incline conveys the materials from the height on which the workshops stand down to the shore of the Firth; the lines of way being then continued on a broad wooden jetty, fifty feet in width, projecting into the Firth for about seven hundred yards, up to the Queensferry main piers, whence springs the southernmost of the two large spans of the bridge.

The island of Inch Garvie, situate in mid-channel, with its group of workshops, offices, &c., necessary for the operations carried on at this isolated and exposed situation, forms the next spot requiring, at present, the use of the electric light.

On the northern, or Fife, shore of the Firth, the operations about the Fife main piers, the northern end of the second of the large spans, together with the branch workshops, stores, &c., connected therewith, as well as portions of the land viaduct extending northwards, and a part of the large stone quarries and shipping stages in the vicinity thereof, are the spots there requiring to be lighted by electricity.

The conditions to be fulfilled in the illumination of the above localities (owing to the ever-changing extent of the demands upon the lighting and the alteration in the position of each light—a matter which varied constantly, with the progress of the work in its vicinity, with the state of the tide, and from other causes) rendered it evident that the details of the arrangements for the lighting must be such as to allow of the requisite changes being effected readily and expeditiously.

Again, it was seen also that portions of the cables, wires, and other working parts of the lighting apparatus would be constantly within reach of the workmen. The primary condition, therefore, demanded a system of lighting simple in its arrangements, and which would inspire confidence in the new illuminant among the workmen.

It became evident, also, that while arc lights would be required for the outside, the offices, residential premises, stores, &c., demanded incandescent lights; and, again, that other buildings, such as the large workshops, necessitated the use of both arc and incandescent lights. Likewise, that the use of storage accumulators, as well as the transmission of power by electricity, might at some time be desirable.

To meet these various conditions it was decided: 1st, to adopt continuous current machines; 2nd, that the type of dynamo for the outside arc lights (limited to six lights in series) should not have a greater E. M. F. than 300 volts between the terminals; 3rd, that the type of dynamo for the incandescent lights, or for the arc and incandescent lights used conjointly, should be on the so-called 'compound-wound' principle, with a maximum E. M. F. of 120 volts between the terminals. The incandescent lamps, in parallel series, used with these machines to have an E. M. F. of 110 volts; while in the large workshops arc lamps in pairs (in series with one another, with the addition of a suitable resistance) would be used, where required, conjointly with the above incandescent lights.

Near to the large workshops are a number of parallel-lines of rails, forming a large uncovered workshop, and termed the 'drill-roads.' Upon these roads circulate large movable huts, each containing an engine, drilling machines, and a circular frame intended for the formation of the various steel tubes of the bridge. Here, as in the large workshops, the use of both arc and incandescent lights is necessary. But, as the exact site where each kind of light might be wanted depended upon the whereabouts of the hut upon the rails, it became necessary to provide for this, at certain fixed points, supply or 'service' boxes, whence readily fixed flexible branch-mains lead the current to the desired site of the lights.

Tenders having been invited for the carrying out of the necessary works, all the lighting on the South Queensferry side was entrusted to, and very efficiently carried out by, Messrs. Siemens Brothers & Co., Limited; while the works on the north side and on Inch Garvie were executed in a very satisfactory manner by Messrs. R. E. Crompton & Co.

The electrical plant contained in the above installations may be stated

briefly, as thirteen dynamo machines, developing about one hundred and fifty electrical horse-power; one hundred large arc lamps (of 2,000 candles each); and five hundred incandescent lamps (of 20 candles each). A total length of about twelve miles of mains has been laid down in the various circuits, exclusive of branch wires to lamps. The lighting by electricity has been carried on continuously and with satisfactory results for nearly two years, by means of the above arrangements. That the peculiar requirements of the situation, together with the storms of winter, have been successfully coped with, attest the careful and thorough manner in which both of the well-known firms who executed the works performed the part entrusted to them.

During that period of working several points of interest have arisen, and among them the following:—

1. The excessively varying conditions which are constantly occurring with regard to the outside arc lights, both as regards the number in actual use, and as to the exact position of each light (dependent greatly upon the character of the particular work going on its vicinity, the state of the tide, &c.), have been satisfactorily met in the following manner. The duty of each series-machine was limited to six arc-lights, as already stated, in order to avoid an excessive E. M. F.; the actual number lighted being varied between one and six at will, by means of resistance-frames. Furthermore, arrangements have been made on a general switch-board by which any of the circuits (sometimes as many as six in one locality) could be coupled with each other, so that the six lights or less, the complement of one machine, might be made to occur, if desired, over a circuit of very varied length (sometimes more than a mile long).

2. The lighting of the large workshops, the drill-roads, &c., demanded a combination of arc and of incandescent lights—the relative proportions between the two kinds being subject to constant variations. It was also necessary that the position should be readily changed, and also that additional lights of either kind might be easily obtainable at will. The use of 'compound-wound' dynamos, with the lamps in parallel circuit (the arc lamps being in pairs, in series with each other, with a suitable resistance in addition), provided for the first condition; while the second was complied with by the use of 'service-boxes,' containing 'plug-sockets,' into each of which was inserted the plug-end forming the extremity of a certain length of flexible twin-leading wire attached to each portable arc or incandescent lamp. The lanterns in which these several lamps were placed varied considerably in form—with arc-lights for outside or for workshop use—while for incandescents, hand-lamps, reflecting bulls-eyes, divers' or miners' lanterns, &c., might be required.

The advantages attached to this mode of working lamps in parallel circuit have proved very considerable. The ease with which lights of either kind can be added to or diminished in number, together with the comparatively low E. M. F. (110 volts), are points which must be in practice appreciated by electrical engineers. At South Queensferry alone as many as 50 arc lights (or, in lieu, 600 incandescents) are being worked on this principle. Great credit is due to Messrs. Siemens on this head, for at the time of their first being used, nothing on so extended a scale on the parallel system existed elsewhere; and certainly the working in pair-series was then quite unique.

3. Perhaps nowhere have more points of interest arisen than in the illumination of the working chambers of the deep-water caissons, which

were constructed to assist in getting in the foundations of the main piers. Each of these circular steel caissons, 60 feet in diameter and rather more in height, has its sides projecting downwards for about 8 feet below the diaphragm or ceiling which extends across the bottom of the cylinder. The lower chamber, which is thus formed, is open-mouthed and becomes a huge diving-bell. In it a number of workmen, having passed down from the surface through a tube 3′ 6″ in diameter, excavate the bottom (passing the *débris* up another tube), and thus gradually sink the caisson to the requisite depth. This operation is, of course, effected under the influence of air compressed according to the height of the water outside.

In the caissons for the Queensferry main piers, where the bottom was of clay, the illumination was effected by means of Swan incandescent lamps, twenty in number, of the ordinary 110 volt, 20 c. p. type, used throughout the works, but each protected by a strong spherical wire-guard for protection from any blow. They were pendent from the ceiling, hung on to a hook or wherever else required; each having a certain length of twin-wire attached, terminating at the other end in a contact plug. The two gutta-percha covered mains, for conveying the electric current from the dynamo, pass from the outer air into the air-lock chamber through a stuffing-box, and thence down the descent-tube into the working chamber, where they are led along the ceiling to a 'distributing-box,' and then, when required, to a second or even a third 'box.' These 'distributing-boxes' each consist of two solid copper rods, kept sufficiently apart and embedded in a wooden block, having a number of square openings in it; each opening exposing sufficient of the copper rods to allow of a good contact being made. This contact is effected by the insertion, when required, of the 'plug-end,' which is at the extremity of the flexible lead attached to each lamp; and which, at the moment of insertion, automatically lights up.

In the caissons at Inch Garvie a different mode of lighting had to be adopted, owing to the rocky bottom, which necessitated blasting; the shock of which would most probably have shattered the incandescent lamps. Here three arc-lamps (of the same type as on the surface) have been used on two circuits working in parallel (a resistance replacing the fourth lamp, which was not required). Above each lamp in the ceiling is a sort of hood, into which it is entirely withdrawn during blasting operations, in order to avoid any damage. A small pipe in the top of this hood leads off the products of combustion into the vertical shaft, and so into the air-lock, whence they are discharged into the air.

The firing of the dynamite charges is performed from the same dynamo which does the lighting. A special pair of mains are carried from the dynamo down the descent-shaft to a distributing-box on the ceiling of the working chamber. The arrangement of the plugs, &c., is the same as for the incandescent lamps, a firing fuse of a very simple construction replacing the incandescent lamp. At the top of the descent-shaft the two firing mains are both severed, and kept permanently in that state. By means of a peculiar double-contact maker, connection can be made instantaneously. When everything is ready for firing, the foreman, who alone has access to the box where is the contact-maker, fires readily the number of charges that may be required. A great deal of the successful working of the lighting arrangements in the caissons, as also in other parts on the surface, is due to the ingenuity and assiduous attention of Mr. Sydney Baynes, the resident electrician at the Forth Bridge Works.

The preceding gives a brief description of the general arrangements which have been in use, so far, for the lighting, not merely of what may be termed the (comparatively) permanent part of the works (such as the offices, stores, workshops, &c.), but also for the actual operations on the foundations of the bridge itself. Shortly this last-named stage will be at an end, and the erection of the superstructure will necessitate, probably, far different arrangements—lights scattered widely and of a very portable character. Then may perhaps come into play, as valuable adjuncts, those two other applications of the electric current—its utilisation in connection with storage accumulators, and for the transmission of power—objects the possibility of the future use of which led the author to adopt continuous current dynamo machines for the lighting by electricity of the Forth Bridge Works.

The New Tay Viaduct. *By* CRAWFORD BARLOW, *B.A.*, *M.Inst.C.E.*

[PLATE VII.]

[A communication ordered by the General Committee to be printed *in extenso* among the Reports.]

CONSIDERABLE interest is attached to this undertaking, because of the comparatively few viaducts of so great length crossing tidal water in such an exposed position, and also because of the fact that it is to replace the Tay Bridge, which was rendered useless by the memorable disaster of December 1879. The Tay Viaduct is being constructed at the side of, and 60 ft. distant from, the bridge, the standing portions of which are used for the conveyance of men and materials, and in otherwise assisting the construction of the new work. The total length is 3,600 yards, *i.e.*, a little over two miles. The number of spans is eighty-five, of dimensions varying from 50 ft. to 230 ft., and the height of the rails above high water where greatest—at the southern end—is 83 ft. At the four navigable spans near the middle of the river the height is 79 ft., which gives a clear headway for shipping of 77 ft.; and from this point to the Dundee or north end there is a falling gradient of 1 in 114, which reduces the rail level at the Dundee end to about 25 ft. above high water.

For the purposes of description the work may be divided into three parts—(1) the arching at Wormit, at the southern end of the viaduct; (2) the Esplanade spans, at the Dundee or northern end; and (3) the viaduct proper, *i.e.*, that part which extends over the tidal water.

1. The arching at Wormit consists of four arches of 50ft. span, with their abutments and piers—Nos. 1 to 4—the whole being built of brick. In plan the width of the arching is equal to that of the viaduct at the northern end, but widens out at the southern end to accommodate the junction of the Newport branch with the Edinburgh main line.

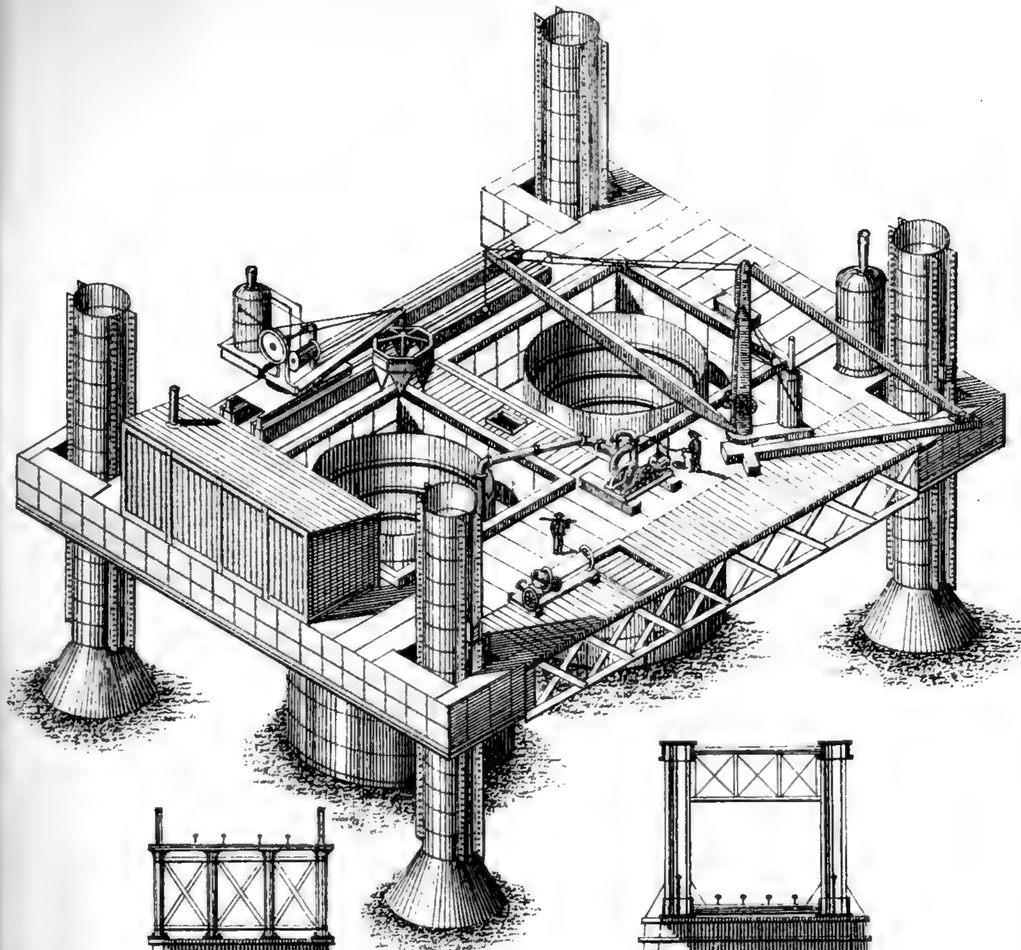
2. The Esplanade spans at the Dundee or north end of the viaduct are seven in number, between piers Nos. 78 and 85, and derive their name from the fact that they cross the existing and proposed extension of the Dundee Esplanade. Two of these spans—between piers 78 and 80—consist of brickwork piers and wrought-iron skew arches, built to suit the direction of the proposed Esplanade; next to these are four spans of wrought-iron girders supported on cast-iron columns, standing on granite and brick-

work bases. The last span is over the existing Esplanade, and consists of a pair of hog-backed girders of 100 ft. span resting on two brick piers.

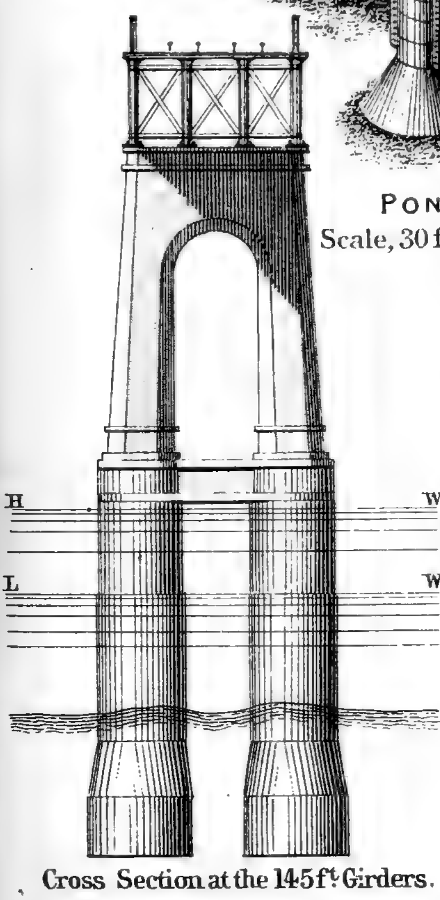
3. The viaduct proper has seventy-four spans of various dimensions, consisting of wrought-iron girders resting on piers—Nos. 4 to 78. The piers are constructed with a pair of cylinders connected at a short distance above high water, and on which is a wrought-iron structure of heights varying from 10 ft. to about 70 ft., the top of which carries the girders. The cylinders of about two-thirds of the piers—Nos. 5 to 53—are constructed with a wrought-iron caisson lined with brickwork and filled with concrete up to low-water level; above this is a brick shaft also filled with concrete. Those for the remaining third—Nos. 54 to 77—are of cast iron lined for their whole height with brickwork, and filled with concrete. The bases of the cylinders are of various diameters—10 ft. for the piers of the smallest spans to 23 ft. for those of the largest; and, except in the few cases where rock is met with, the cylinders are being sunk to depths varying from 20 ft. to 30 ft. below the bed of the river, so as to be out of reach of the scouring action of the tide. Before building the upper part, the cylinder foundations are tested with a weight 33 per cent. greater than the maximum load which can come upon them. At $1\frac{1}{2}$ ft. above high water there is a strong connecting piece between the pair of cylinders constructed with cast-iron girders, wrought-iron ties, brickwork and concrete; its height is 8 ft., and width nearly equal to that of the cylinders. On the top of each cylinder and above the connecting piece rises an octagonal shaft of wrought-iron, the base of which is formed of a gridiron framework of channel irons attached to the cylinders by long wrought-iron bolts. These shafts are joined together near the top of the pier by a semicircular arch, forming at the top one structure sufficiently wide to carry the girders. The whole of this structure is constructed of wrought-iron plates, riveted together with channel, Tee, and angle irons. The dimensions of the girders for the seventy-four spans are very various, and are as follows:—Eleven spans with 245 ft. girders, two spans with 227 ft. girders, one span with 162 ft. girders, thirteen spans with 145 ft. girders, twenty-one spans with 129 ft. girders, one span with 113 ft. girders, twenty-four spans with 71 ft. girders, and one span with 56 ft. girders. The thirteen large spans, with 245 ft. and 227 ft. girders—between piers 28 and 41—are near the middle, and over the navigable channel of the river. At each of these spans there is a pair of hog-backed girders, the rails being laid between and at the bottom of them. The rest of the spans—twenty-four on the south side, and thirty-seven on the north side—are constructed with four rectangular girders, the two outer ones being the girders of the old bridge. At these spans the rails are laid on top of the girders. The flooring or deck plating is corrugated in form, and is constructed, at the large spans, of channel irons and plates riveted together, so as to form alternate troughs and ridges; and at the smaller spans of steel plates hydraulically pressed into a corrugated shape.

On each side of the viaduct for its whole length is a wrought-iron latticework parapet or wind screen 5 ft. high above the rails.

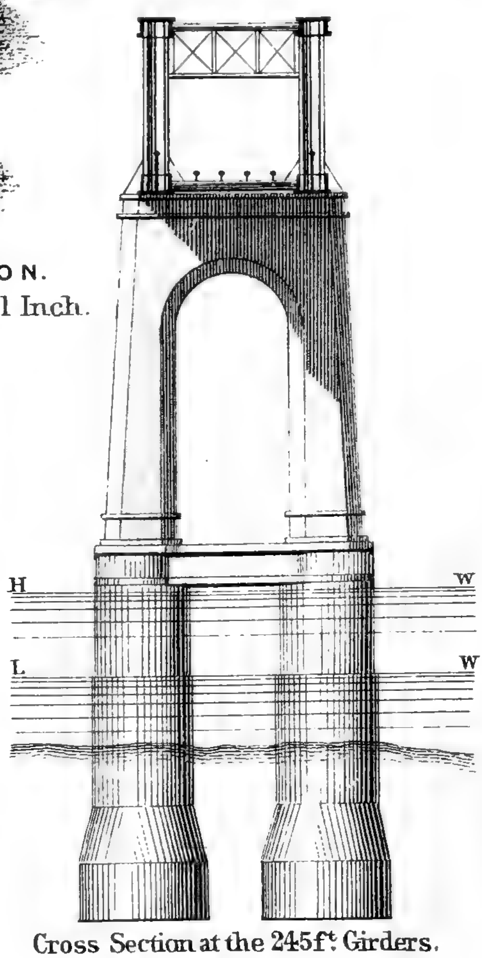
The Act of Parliament for the undertaking was obtained in 1881, but the contract for the works was not settled until April 1882, owing to a question raised with the Board of Trade concerning the ruins and *débris* of the old bridge. The present state of the works is as follows:—The arching at Wormit and the Esplanade spans are completed to the level of



PONTOON.
Scale, 30 ft. to 1 Inch.



Cross Section at the 145 ft. Girders.



Cross Section at the 245 ft. Girders.

Scale, 40 ft. to 1 Inch.

Spottiswoode & Co. Lith. London.

Illustrating Mr. Crawford Barlow's Paper on the "New Tay Viaduct."

the railway, and the greater part of the parapets of the Esplanade spans is erected. At the viaduct proper the cylinders for fifty-eight out of the total of seventy-three piers have been sunk. The method adopted by Messrs. Arrol, the contractors for the works, for sinking them is specially ingenious. It consists of a rectangular pontoon, having at each of its corners vertical wrought-iron tubular legs, which can be raised or lowered hydraulically. When these are lowered to the bed of the river the pontoon can be raised out of the water, and thus form a stage for the machinery, materials, and men required in sinking and filling the cylinders. In the pontoons are two openings, within which the cylinders are pitched and adjusted in position. The excavation is effected by means of steam diggers, and as the digging proceeds the cylinders follow down, until the required depth is reached. When the sinking and filling is completed, the supporting tubes or legs are raised from the bottom, and the pontoon floated into position for another pier. It may be mentioned that, in raising or lowering these legs, great use is made of the tide. Four of these pontoons have been used for sinking the cylinders. The wrought-iron structures or shafts of four piers on the south side, and of twenty-four piers on the north side, have been erected. The girders for one span on the south side and nine spans on the north side are erected in position on the piers, and nearly all the girders, except those for the large spans, are built and ready for erection. The girders and flooring for each of the thirteen large spans are being built entire on a staging erected for this purpose at the south end of the viaduct, and arrangements are being made by which the girders and flooring for each span complete will be floated out to position in the viaduct, and placed on the cylinders; they will then be raised hydraulically to their proper height, the wrought-iron shafts of the piers being built up at the same time. The general progress of the whole viaduct may be briefly stated to be as follows:—Nearly seven-eighths of the foundations of the eighty-six piers are put in; almost one-half of the piers are built up to the level of the girders, &c., and out of the total length of 3,600 yards, 540 yards—*i.e.* rather more than one-eighth—is complete and ready for the railway. All the wrought-iron and steel for the work is carefully tested, the tests being that the wrought-iron must be capable of bearing a tensile strain of 22 tons per square inch, with an extension of 6·25 per cent. in a length of 8 in.; and the steel 27 tons per square inch, with an extension of 15 per cent. The whole of the iron and steel work is shaped and drilled at Messrs. William Arrol & Co.'s works at Glasgow, preparatory for erection either on the shores or in position in the viaduct. In executing these works a great amount of plant is required, and a number of ingenious machines and clever contrivances have been devised and brought into operation by the contractors for the better performance of the work and saving of labour.

TRANSACTIONS OF THE SECTIONS.

TRANSACTIONS OF THE SECTIONS.

Section A.—MATHEMATICAL AND PHYSICAL SCIENCE.

President of the Section—Professor G. Chrystal, M.A., F.R.S.E.

THURSDAY, SEPTEMBER 10.

The President delivered the following Address:—

When a man finds himself unexpectedly in some unusual situation his first impulse is to look round and see how others have done in like circumstances. I have accordingly run through the addresses of my predecessors in the honourable office of president of Section A, which is fated this year to be filled somewhat unworthily. This examination has, I am bound to say, comforted me not a little. I have found precedents for all kinds of addresses, long and short, even apparently for none at all. The variety of subjects is also suggestive of great latitude. I have found reviews of the progress of mathematical and physical science, discussions of special scientific subjects, dissertations on the promotion of scientific research, and on the teaching and diffusion of science, all chosen in their turn for the subjects of this opening address.

Following some of the most eminent of my forerunners, I propose to be brief; following the last of them, Professor Henrici, I shall take for my subject, so far as I have one, the Diffusion of Scientific Knowledge. Apart from the fact that Professor Henrici's address greatly interested me, and that I find many of his conclusions in agreement with the results of my own experience, and that, therefore, I wish to second him with all my power, I have other reasons for this choice. For more than half the year I am employed with absolute continuity in teaching mathematics, and it has happened for the last eight years or so that the other half has been mainly occupied in a variety of ways with science-teaching generally. This is the thing concerning which I have had most experience, and I hold it to be the most respectful course towards my audience to speak to them on the subject that I know best.

Ever since I began to study science I have been deeply interested in the question of how it could best be taught. I believe my meditations in that direction were awakened by some unsuccessful boyish efforts to apply to the satisfaction of a ploughman, who was my friend and confidant, certain principles of natural philosophy to explain the action of his plough. Wisely and unwisely I have always been ardent about the improvement of scientific teaching. I was so long before I dreamt that I should one day be called upon to put my ideas through the cold ordeal of practice. It would not be becoming that I should speak at any time, more particularly to-day, regarding the success of my own efforts, or even regarding my alternate fits of hopefulness and despair. It is enough to say that, in such a cause,

> ''Tis better to have loved and lost,
> Than never to have loved at all.'

The British Association, by its title, exists for the advancement of science. Now, I hold that one of the essential conditions for that advancement is the existence of a scientific public—a public, like the Athenians of old, eager to hear and tell of some new truth; eager to discuss and eager to criticise; ready to appreciate what is novel; to receive it if sound, to reject it if unsound. It is to such a public that the British Association appeals, and certainly in the past it has not found its public wanting in generosity. What I should wish to see is less of mere friendly onlooking and more participation in the dance.

I am not speaking now merely of a professional public, such as is so prominent in Germany for instance, made up of teachers and others professionally concerned with science. I refer mainly to that amateur but truly expert public which has always been so honourable a feature of English science, as examples of which I may mention Boyle and Cavendish in former days, and Joule and Spottiswoode in our own. It is quite true that much of that scientific public came in days of yore from the leisured class, whose ratio to the rest of the nation will not improbably decrease in the course of our social development. I think, however, that the loss we may thus sustain will be more than compensated by the continual increase of those who have received higher education of some kind or other, and whose daily occupations give them an interest, direct or indirect, in one or more branches of science.

It may not be amiss to insist for a little on the advantages to science of a great body of men unofficially engaged in scientific research, in writing regarding science, or even in merely turning scientific matter over in their minds. It will not have escaped the notice of those among you who have studied the history of science, that few scientific ideas spring up suddenly without previous trace or history. It is perfectly true that in many cases some mind of unwonted breadth and firmness is required to formulate the new doctrine, and carry it to manifold fruition; but a close examination always shows that the sprite was in the air before the Prospero came to catch him. It is very striking to notice, in the history of Algebra for instance, long periods in which great improvements were effected in the science, which cannot be traced to any individual, but seem to have been due merely to the working of the minds of scientific men generally upon the matter, one giving it this little turn, another that, in the main always for the better. Like every other thing that has the virtue of truth in it, science grows as it goes, not like the idle gossiping tale by the casual accretion of heterogeneous matter, but by the chemical combination of pure element with pure element in reasonable proportion.

I know of no greater advantage for science than the existence of an army of independent workers sufficiently enlightened for self-criticism, who shall test the results and theories of their day. Great and indispensable as are the uses of professional schools of scientific workmen, they are open to one great and insidious danger. The temptation there to swear by the word of the master is often irresistible. Not to speak of its being often the readiest avenue to fame and profit, it is the perfectly natural consequence of the contact of smaller mind with greater.

There are few things where the want of an enlightened scientific public strikes an expert more than the matter of scientific text-books. If the British public were educated as it ought to be, publishers would not be able to palm off upon them in this guise the ill-paid work of fifth-rate workmen so often as they do; nor would the scientific articles and reviews in popular journals and magazines so often be written by men so palpably ignorant of their subject.

We all have a great respect for the integrity of our British legislators, whatever doubts may haunt us occasionally as to their capacity in practical affairs. The ignorance of many of them regarding some of the most elementary facts that bear on everyday life is very surprising. Scientifically speaking, uneducated themselves, they seem to think that they will catch the echo of a fact or the solution of an arithmetical problem by putting their ears to the sounding-shell of uneducated public opinion. When I observe the process which many such people employ for arriving at what they consider truth, I often think of a story I once heard of an eccentric German student of chemistry. This gentleman was idle, but, like all his nation, systematic. When he had a precipitate to weigh, instead

of resorting to his balance, he would go the round of the laboratory, hold up the test-tube before each of his fellow-students in turn, and ask him to guess the weight. He then set down all the replies, took the average, and entered the result in his analysis.

I will not take up your time by insisting upon the necessity of the diffusion of science among that large portion of the public who are, or ought to be, appliers of scientific knowledge to practical life. That part of my theme is so obvious, and has been of late so much dwelt upon, that I may pass it by and draw your attention to another place in which the shoe pinches. All of you who have taken any practical interest in the organisation of our educational institutions must be aware of the great difficulty in securing the services of non-professional men of sufficient scientific knowledge to act on School Boards, and undertake the direction of our higher schools. It is no secret among those who carefully watch the course of the times in these matters that our present organisation is utterly insufficient; that it has not solved, and shows every day less likelihood of solving, the problems of higher education. This arises, to a great extent, from the fact that a scientifically educated public of the extent presupposed by the organisation really does not at present exist.

If the existence of a great scientific public be as important as I think I have shown it to be, it must be worth while to devote a few moments to the consideration of the means we adopt to produce it both in the rising and in the risen generation.

It would naturally be expected that we should look carefully to the scientific education of our youth, to see that the best men and the best means that could be had were devoted to it; that we should endeavour to make for them a broad straight road to the newest and best of our scientific ideas; that we should exercise them when young on the best work of the greatest masters; familiarise them early with the great men and the great feats of science, both of the past and of the present; that we should avoid retarding their progress by making the details and illustrations or particular rules and methods ends in themselves. Granting that it is impossible to bring every learner within reach of the fullest scientific knowledge of his time, it would surely be reasonable to take care that the little way we lead him should not be along some devious by-path, but towards some eminence from which he might at least *see* the promised land. The end of all scientific training of the great public I take to be, to enable each member of it to look reason and nature in the face, and judge for himself what, considering the circumstances of his day, may be known, and not be deceived regarding what must to him remain unknown. If this be so, surely the ideal of scientific education which I have sketched is the right one: yet it is most certainly not the ideal of our present system of instruction. To attain conviction on that head it is sufficient to examine the text-books and examination papers of the day.

Let us confine ourselves for the present to the most elementary of all the exact sciences, viz., geometry and algebra. These two, although among the oldest, are, as Professor Cayley very justly reminded the Association not long ago, perhaps the most progressive and promising of all the sciences. Great names of antiquity are associated with them, and in modern times an army of men of genius have aided their advance. Moreover, it cannot be said that this advance concerns the higher parts of these sciences alone. On the contrary, the discoveries of Gauss, Lobatschewsky, and Riemann, and of Poncelet, Möbius, Steiner, Chasles, and Von Staudt, in geometry, and the labours of De Morgan, Hamilton, and Grassmann, not to mention many others, in algebra, have thrown a flood of light on the elements of both these subjects. What traces of all this do we find in our school books? To be sure *antiquity* is stamped upon our geometry, for we use the text-book of Euclid, which is some two thousand years old; but where can we point to the influence of *modern* progress in our geometrical teaching? For our teaching of algebra, I am afraid, we can claim neither the sanction of antiquity nor the light of modern times. Whether we look at the elementary, or at what is called the higher teaching of this subject, the result is unsatisfactory. With respect to the former, my experience justifies the criticism of Professor Henrici; and I have

no doubt that the remedy he suggests would be effectual. In the higher teaching, which interests me most, I have to complain of the utter neglect of the all-important notion of algebraic form. I found, when I first tried to teach University students co-ordinate geometry, that I had to go back and teach them algebra over again. The fundamental idea of an integral function of a certain degree, having a certain form and so many coefficients, was to them as much an unknown quantity as the proverbial x. I found that their notion of higher algebra was the solution of harder and harder equations. The curious thing is that many examination candidates, who show great facility in reducing exceptional equations to quadratics, appear not to have the remotest idea beforehand of the number of solutions to be expected; and that they will very often produce for you by some fallacious mechanical process a solution which is none at all. In short, the logic of the subject, which, both educationally and scientifically speaking, is the most important part of it, is wholly neglected. The whole training consists in example grinding. What should have been merely the help to attain the end has become the end itself. The result is that algebra, as we teach it, is neither an art nor a science, but an ill-digested farrago of rules, whose object is the solution of examination problems.

The history of this matter of problems, as they are called, illustrates in a singularly instructive way the weak point of our English system of education. They originated, I fancy, in the Cambridge Mathematical Tripos Examination, as a reaction against the abuses of cramming bookwork, and they have spread into almost every branch of science teaching—witness test-tubing in chemistry. At first they may have been a good thing; at all events the tradition at Cambridge was strong in my day, that he that could work the most problems in three or two and a half hours was the ablest man, and, be he ever so ignorant of his subject in its width and breadth, could afford to despise those less gifted with this particular kind of superficial sharpness. But, in the end, it came all to the same: we were prepared for problem-working in exactly the same way as for bookwork. We were directed to work through old problem papers, and study the style and peculiarities of the day and of the examiner. The day and the examiner had, in truth, much to do with it, and fashion reigned in problems as in everything else. The only difference I could ever see between problems and bookwork was the greater predominance of the inspiriting element of luck in the former. This advantage was more than compensated for by the peculiarly disjointed and, from a truly scientific point of view, worthless nature of the training which was employed to cultivate this species of mental athletics. The result, so far as problems worked in examinations go, is, after all, very miserable, as the reiterated complaints of examiners show; the effect on the examinee is a well-known enervation of mind, an almost incurable superficiality, which might be called Problematic Paralysis—a disease which unfits a man to follow an argument extending beyond the length of a printed octavo page. Another lamentable feature of the matter is that an enormous amount of valuable time is yearly wasted in this country in the production of these scientific trifles. Against the occasional working and propounding of problems as an aid to the comprehension of a subject, and to the starting of a new idea, no one objects, and it has always been noted as a praiseworthy feature of English methods, but the abuse to which it has run is most pernicious.

All men practically engaged in teaching who have learned enough, in spite of the defects of their own early training, to enable them to take a broad view of the matter, are agreed as to the canker which turns everything that is good in our educational practice to evil. It is the absurd prominence of written competitive examinations that works all this mischief. The end of all education nowadays is to fit the pupil to be examined; the end of every examination not to be an educational instrument, but to be an *examination* which a creditable number of men, however badly taught, shall pass. We reap, but we omit to sow. Consequently our examinations, to be what is called fair—that is, beyond criticism in the newspapers—must contain nothing that is not to be found in the most miserable text-book that any one can cite bearing on the subject. One of my students, for

example, who was plucked in his M.A. examination, and justly so if ever man was, by the unanimous verdict of three examiners, wrote me an indignant letter because he believed, or was assured, that the paper set by the examiners could not have been answered out of Todhunter's Elementary Algebra. I have nothing to say, of course, against that or any other text-book, but who put it into the poor young man's head that the burden lay with me to prove that the examination in question ought to contain nothing but what is to be found in Todhunter's Elementary Algebra? The course of this kind of reasoning is plain enough, and is often developed in the newspapers with that charming simplicity which is peculiar to honest people who are, at the same time, very ignorant and very unthinking. First, it follows that lectures should contain nothing but what is to be found in every text-book; secondly, lectures are therefore useless, since it is all in the text-book; thirdly, the examination should allude to nothing that is not in the text-books, because that would be unfair; fourthly, which is the coach or crammer's deduction, there should be nothing in the text-book that is not likely to be set in the examination. The problem for the writer of a text-book has come now, in fact, to be this—to write a booklet so neatly trimmed and compacted that no coach, on looking through it, can mark a single passage which the candidate for a minimum pass can safely omit. Some of these text-books I have seen, where the scientific matter has been, like the lady's waist in the nursery song, compressed 'so gent and sma',' that the thickness of it barely, if at all, surpasses what is devoted to the publisher's advertisements. We shall return, I verily believe, to the Compendium of Martianus Capella. The result of all this is that science, in the hands of specialists, soars higher and higher into the light of day, while educators and the educated are left more and more to wander in primeval darkness.

When our system sets such mean ends before the teacher, and encourages such unworthy conceptions of education, is it to be wondered at that the cry arises that pupils degenerate beneath even the contemptible standards of our examinations? These can hardly be made low enough to suit the popular taste. It is no merit of the system we pursue, but due simply to the better among our teachers, men many of them who work for little reward and less praise, that we have not come to a worse pass already. Some even of the much-abused crammers have conceptions of a teacher's duty far higher than the system-mongers of the day, whom it is their special business to outwit; and it is but fair to allow to such of these also as deserve it part of the credit of stemming the torrent of degeneration. We place our masters in positions such that their very bread depends upon their doing what many of them know and will acknowledge to be *wrong*. Their excuse is, 'We do so and so because of the examination.'

The cure for all this evil is simply to give effect to a higher ideal of education in general, and of scientific education in particular. Science cannot live among the people, and scientific education cannot be more than a wordy rehearsal of dead text-books, unless we have living contact with the working minds of living men. It takes the hand of God to make a great mind, but contact with a great mind will make a little mind greater. The most valuable instruction in any art or science is to sit at the feet of a master, and the next best to have contact with another who has himself been so instructed. No agency that I have ever seen at work can compare for efficiency with an intelligent teacher, who has thoroughly made his subject his own. It is by providing such, and not by sowing the dragon's teeth of examinations, that we can hope to raise up an intelligent generation of scientifically educated men, who shall help our race to keep its place in the struggle of nations. In the future we must look more to men and to ideas, and trust less to mere systems. Systems have had their trial. In particular, systems of examination have been tested and found wanting in nearly every civilised country on the face of the earth. Backward as we are here, we are stirring. The University of London, after rendering a great service to the country by forcing the older universities to give up the absurd practice of restricting their advantages to persons professing a particular shade of religious belief, has for many years pursued its career as a mere examining body. It has done so with rare advantages in the way of Government aid, efficient organisation, and an unsurpassed staff

of examiners. Yet it has been a failure as an instrument for promoting the higher education—foredoomed to be so, because, as I have said, you must sow before you can reap. At the present time, with great wisdom, the managers of that institution have set about the task of really fitting it out for the great end that it professes to pursue. If they succeed in so doing, they will confer upon the higher education one of the greatest benefits it has yet received. They have an opportunity before them of dethroning the iron tyrant Examination which is truly enviable. This movement is only one of the signs of the times. Among the younger generation I find few or none that have any belief in the 'learn when you can and we will examine you' theory; and small wonder, for they have tasted the bitterness of its fruit. *Laissez faire* as a method in the higher education no longer holds its place, except in the minds of inexperienced elderly people, who cling, not unnaturally, to the views and fashions which were young when they were so.

All the same, the task of reformation is not an easy one. Examinations have a strong hold upon us, for various reasons, some good, some bad, but all powerful. In the first place, they came in as an outlet from the system of patronage, which, with many obvious advantages, some of which are now sorely missed, had become unsuited to our social conditions. There is a certain advantage in examinations from the organiser's point of view, which any one who, like myself, has to deal with large quantities of pretty raw material will readily understand. Again, there is an orderly bustle about the system that pleases the business-loving eye of the Briton. Yearly the printed sheets go forth in every corner of the land. The candidates meet and, in the solemn silence of the examination hall, the inspector, the local magnate, or the professor, sits, while for two or three busy hours the pens go scratching over the paper. A feeling of thankfulness comes over the important actor in this well-ordered scene, that the younger generation have such advantages that their fathers never knew. It is only when the answers are dissected in the examiner's study that the rottenness is revealed underlying the fair outward skin. But then the examiner must go by his standards; he must consider what is done elsewhere, and what is to be reasonably expected. Accordingly he takes his report and quickly writes so many per cent. passed. Then the chorus of reporting examiners lift up their voices in wonderful concordance; and all, perhaps even the examiners, are comforted. There is something attractive about the whole thing that I can only compare to the pleasure with which one listens to the hum of a busy factory or to the roaring of the forge and ringing of the anvil. But what avails the hum of the factory if the product be shoddy, and what the roar of the forge and the ring of the anvil if the metal we work be base?

In conclusion, let us consider for a moment what might be done for the risen generation, who are too old to go formally to school, and yet not too old to learn. In their education such bodies as the British Association might be very helpful. Indeed, in the past, the British Association has been very helpful in many ways. It can point to an admirable series of reports on the progress of science, for which every one who, like myself, has used them, is very grateful. It is much to be desired that these reports should be continued, and extended to many branches of science which they have not yet covered.

The Association has at present, I believe, a committee of inquiry into science-teaching generally. This is typical of a kind of activity which the Association might very profitably extend. This Association, with its long list of members bristling with the names of experts in every science, not drawn from any clique or particular centre, but indiscriminately from the whole land, might take upon itself to look into the question of scientific text-books and treatises. Even if it did not set up a censorship of the scientific press, which might be an experiment of doubtful wisdom, although some kind of interference seems really wanted now and then, it might set itself to the highly useful work of filling the gaps in our scientific literature. There is nothing from which the English student suffers so much as the want of good scientific manuals. The fact is that the expense of getting up such books in this country is so great, and the demand for them, though steady, yet so limited, that it will not pay publishers to issue them, let alone

remunerate authors to write them. In my student-days the scarcity was even greater than it is now, and in fact then no one could hope to get even a reasonable acquaintance with the higher branches of exact science unless he had some familiarity with French or German at the very least—a familiarity which was rare among my fellow-students either in England or in Scotland. Might not the British Association now and then request some one fitted for the task to write a treatise on such and such a subject, and offer him reasonable remuneration for the time, labour, and skill required?

Another field in which the Association might profitably extend its labours appears to me to be the furnishing of reports, from time to time, on the teaching of science in other countries, and the drawing up of programmes of instruction for the guidance of schoolmasters and of those who are reading for their own instruction. There is no need to impose these programmes on any one. I would leave as much freedom to the teacher as I would to the private student. The programme drawn up by the Society for the Improvement of Geometrical Teaching, for example, has been very useful to me as a teacher, although I do not follow it or any other system exclusively. The great thing is not to fall asleep over any programme or system. For the matter of that, Euclid would do very well in the earlier stages of school instruction at least, provided he were modernised, and judiciously discarded at that part of the student's career where a lighter vehicle and more rapid progress becomes necessary. In such programmes as I contemplate the bearing of recent discovery on the elements of the various sciences could be pointed out, and the general public kept in this way from that gross ignorance into which they are at present allowed to fall.

The British Association has of late, I believe, given its attention to the encouragement of local scientific activity. There can be no doubt that much could be done in this way that is not done at present. The concentration of scientific activity in metropolitan centres is beginning to have a depressing effect in Great Britain. This is seen in the singularly unequal way in which Government aid is distributed over the country. Large sums are spent—sometimes we outsiders think not to the best purpose—through certain channels, simply because these channels happen to have a convenient opening in some Government office in London, or in some place in that important city which has easy access to the ruling powers; while applications on behalf of other objects not less worthy are met with a refusal which is sometimes barely courteous. The result is that local effort languishes, and men of energy, finding that nothing can be done apart from certain centres, naturally gravitate thither, leaving provincial desolation to become more desolate.

I think our great scientific societies—the Royal Societies of London and Edinburgh and the Royal Irish Academy—might do more than they do at present to prevent this languishing of local science, which is so prejudicial to the growth of a scientific public. Besides their all-important publishing function, these bodies have for a considerable time back been constituted into a species of examining and degree-conferring bodies for grown-up men. That is to say, their membership has been conferred upon a principle of *exclusion*. Instead of any one being *admitted* who is willing to do his best, by paying his subscription or otherwise, to advance science, every one is *excluded* who does not come up to the standard of a certain examining body. So far is this carried in the case of the Royal Society of London, that there is an actual competitive examination, on the result of which a certain number of successful candidates are annually chosen. Now, against this proceeding by itself I have nothing to say, except that it appears to belong to the pupillary age both of men and nations. It is not the honouring of the select few that I think evil, but the exclusion of the unhonoured many. The original intention in founding these societies was to promote the advancement of science. How that is done by excluding any one, be it the least gifted among us, who is honestly willing to contribute his mite towards the great end, fairly passes my comprehension. If it is thought necessary, for the proper cultivation of the scientific spirit among us, that the degree-conferring function should be continued, let there by all means be an inner court of the temple, a place for titular immortals; but let there

be also a court of the Gentiles, where those whose fate or whose choice it is to serve science unadorned may find a modest reception. I believe that the adoption of this suggestion would enormously extend the usefulness of our great scientific societies, and give to their voice a weight which it never had before. At all events, if the trammels of tradition, or some better reason with which I am unacquainted, should prevent them from broadening their basis in the way I indicate, nothing prevents the British Association, with its more liberal constitution, from considering what may be done for the scientific plebeian.

There is one other function of the British Association in connection with which I wish to venture another suggestion. During the annual meeting, scientific men have an opportunity of making each other's acquaintance. Great men exchange ideas with great men; and, most important of all, young and little men have a chance, rarely otherwise afforded, of taking a nearer view of the great. What I would suggest for consideration is, whether it might not be possible to form an organisation which would in a certain sense carry this advantage through the whole year. I have already alluded more than once to the difficulties that the scientific public—and here I include professional men generally, in fact all but the leaders of science—have in keeping pace with recent advances. Would it not be possible to have an arrangement enabling at least every large centre of the higher education to have periodically the benefit of communion with and instruction from the high priests of the various branches of science? How glad we, the teachers of science in Edinburgh for example, would be to have a course of lectures once every three or four years from Professors Cayley, Sylvester, Stokes, Adams, or Lord Rayleigh. In this way effect would be given to the principle which cannot be too much insisted upon, that the power of the spoken word far exceeds that of the written letter. Not only should we learn from the mouths of the prophets themselves the highest truths of science, but the present generation would thus come to know face to face, as living men, those whose work will be the glory of their time and a light for future ages. From the want of a proper circulating medium, the influence of great scientific men very often does not develop until they and the secrets of their insight have gone from among us. The object of what I propose is to make these men more of a living power in their own lifetime.

The following Papers were read:—

1. *On the Dilatancy of Media composed of Rigid Particles in Contact.*[1] *By* Professor OSBORNE REYNOLDS, *M.A., F.R.S.*

In the account which Professor Reynolds gave of his paper, he did not submit a complete dynamical theory, but discussed a very fundamental property of granular masses. To this property he gives the name of *dilatancy*. It is exhibited in any arrangement of particles where change of bulk is dependent upon change of shape. In the case of fluid matter, as we know it, change of shape and volume are independent. In solids they are sometimes not separable. With granular masses the result is different—change of shape *always* produces change of volume. And further, in every case, if change of volume is prevented all change of form is impossible.

If we suppose the granular masses to be spherical, no granule can change its position without disturbing the adjacent particles—for the granules are all supposed to be perfectly rigid, and to be absolutely in contact; and the internal particles are fixed if the external ones are. In illustration Professor Reynolds showed a model of connected spherical bodies arranged in crystalline form. This model showed the arrangement of the particles corresponding to, say, the condition of least possible density of the whole mass (about one-half the density of the separate spheres). The shape could then be altered to that which corresponds to maximum density—the change taking place by sliding of the particles one upon another. Between the extreme states there are intermediate stages of equilibrium corresponding to maximum-minimum positions, where alteration in one direction produces decrease of density, and in the other increase of density.

[1] Published in full in *Phil Mag.* Dec. 1885, p. 469.

In a complete treatment of the problem, friction must be closely considered; but in the experiment shown it is not of consequence, the result being independent. The above statements will be true of any continuous mass of granules if we hold the boundaries.

This principle of the dilatancy of such granular media explains many phenomena of common occurrence. For example, take a sack of corn, if set on end, it remains perfectly flexible; but if placed on its side it becomes hard, and its shape will not alter. Now take an indiarubber sack, fill it with shot—it remains perfectly flexible in all positions. The reason for this difference of behaviour is that in the former case the boundary of the granular mass is inextensible, while in the latter it allows increase of internal volume. So if it be possible with an extensible envelope to impose a limit to the volume of the contents, effects similar to those obtained with the inextensible boundary may be expected: and this can be done. If we place some shot (No. 6 was used in the experiment) in a thin indiarubber bag, and add a certain amount of water, we obtain the result wished. For if the amount of water added be such that the spaces between the granules when in close arrangement are all filled by it, while with a wide arrangement the amount is not enough, a point will be reached in passing from the first to the second arrangement such that any further change of volume, and consequently of shape, would produce a vacuum. When this stage is reached the whole mass becomes perfectly hard. Professor Reynolds illustrated this by means of a ball of shot to which a glass tube open at the end was fitted. With a close arrangement of the shot, the water, which was coloured, stood high in the tube; but when pressure was applied to the bag, the level was lowered. This was shown also with a ball containing sand instead of shot. The water level sank till the whole was at maximum density, and, still more pressure being applied, the level again rose, the maximum having been passed. In these experiments about 6 per cent. of the water was free at the top of the ball with the close arrangement of granules. When another ball containing 20 per cent. of free water was used, the hard condition could only be approximated to by pressure, and then passed. So long as the maximum is not passed in this case the ball springs back to its original state when the pressure is released. But if the maximum be passed, it will not spring back. If some of the water be now let out, the maximum cannot be passed, except by shaking, and, if the flattened ball be then turned on edge, it will bear a pressure of a hundred weight without change of shape.

When the dilatant material, such as shot or sand, is bounded by smooth surfaces, the layer of grains adjacent to the surface is in a condition differing from that of the grains within the mass. This layer can slide between the one succeeding it and the surface, causing much less dilatation than would be caused by the sliding of a layer within the mass. Hence, if two parts of the mass are connected by such a surface, certain conditions of strain may be accommodated by a streaming motion of the grains next the surface. Thus, if into a glass funnel partially filled with shot and held in a vertical position more shot be forced from below, the particles will flow up all around the sides—not rising in the centre as might have been thought.

As the foot presses upon the sand when the falling tide leaves it firm, that portion of it immediately surrounding the foot becomes momentarily dry. When this happens the sand is filled, completely up to its surface, with water raised by capillary attraction. The pressure of the foot causes dilatation of the sand, and so more water is required. This has to be obtained either by depressing its level against the attraction or by drawing it through the interstices of the surrounding sand. As this latter requires time, for the moment the capillary forces are overcome, and the surface of the water is lowered below that of the sand, leaving it dry until a sufficient supply has been obtained from below, when it again becomes wet. On raising the foot we generally see that the sand under and around it becomes wet for a little time. This is because the sand contracts when the distorting forces are removed, and the excess of water escapes at the surface.

In referring to the results which might be expected to follow from a recognition of the property of dilatancy, the author said that it places a hitherto unknown

mechanical contrivance at the command of those who would explain the fundamental arrangement of the universe, and one which seems to promise great things besides possessing the inherent advantage of great simplicity. He then proceeded to explain, in a general way, how bodies in such a medium would—in virtue of the dilatation caused in the medium—attract each other at a distance, with a force depending on the distance, which might well correspond with the force of gravitation. Further, owing to the existence of a region close to the body in which the density varies several times from maximum to minimum, the mutual force might undergo a change from attraction to repulsion, and this more than once as the bodies approach—a condition which seems to account for cohesion and observed molecular force far better than any previous hypothesis.

The transmission of distortional waves becomes possible if the medium be composed of small grains with large grains interspersed. The separation of two such sets of grains leads to phenomena closely resembling the phenomena of statical electricity. The susceptibility of such a medium for a state in which the two sets of grains are in conditions of opposite distortions may explain electrodynamic and magnetic phenomena, while the observed conducting power of a continuous surface for the grains of a simple dilatant medium closely resembles the conduction of electricity.

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2. *On Calculating the Surface Tension of Liquids by means of Cylindrical Drops or Bubbles. By* Professor G. Pirie, *M.A.*

The author asserted that surface tensions are found only approximately and with difficulty by measuring the dimensions of round drops. He suggested that cylindrical drops should be used. He worked out the theory and described experiments of verification.

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3. *On the Surface Tension of Water which contains a Gas dissolved in it. By* Professor G. Pirie, *M.A.*

The object of the experiments was to discover if water, which holds a gas in solution, has a different surface tension from water which holds no gas; and if it has to discover the law according to which increasing quantities of gas absorbed affect the capillarity.

It was found that the surface tension is not measurably affected by those gases which, like air and carbonic acid, are not absorbed in sufficient quantities to affect markedly the specific gravity. A table of values of the specific cohesion was given for different quantities of two gases which are absorbed in large quantity.

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4. *Thermodynamic Efficiency of Thermopiles.*[1] *By* Lord Rayleigh, *D.C.L., LL.D., F.R.S.*

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5. *On the Measurement of the Intensity of the Horizontal Component of the Earth's Magnetic Field.*[2] *By* Thomas Gray, *B.Sc., F.R.S.E.*

The general principle of the method adopted was that of Gauss, with these modifications. In the deflection experiment the magnetometer needle was made so short that in the calculations it could be assumed without sensible error to be of zero length, and two deflectors were used simultaneously. The deflectors were placed one on each side of the magnetometer needle, with their axes in a line at right angles to the magnetic meridian; and in position for deflecting the needle the direction of the line passing through the centres of the deflectors and the magnetometer needle, were: first, the magnetic meridian, and second, a line at right angles

[1] Published in *Phil. Mag.* Oct. 1885.
[2] Published in *Phil. Mag.* Dec. 1885.

to it. The author pointed out that this mode of procedure leads to two equations which suffice for the determination of the horizontal component of the earth's magnetic field, and also of the effective length of the deflector. In these equations he also showed that the length of the deflector entered as a minus term in the one and plus in the other, and thus rendered the observations highly sensitive to possible errors in that term, and enabled a good estimate of the effective length of the different deflectors to be had. Apparatus was described by which the whole cycle of observations, both for this and the oscillation experiment, might be obtained without the necessity of handling the deflector magnets.

The effects of the various corrections on the value of 'H' derived from the equations were discussed. Such of the errors as were sensible had been made the subject of direct experiment, and their effect allowed for in the table of values of 'H' given in the paper and quoted below.

As the observations necessary for a determination of 'H' by this method extend over such a time as may make the diurnal variation sensible, and further to guard against the readings being vitiated by undetected magnetic storms, a magnetic vibrator was kept going throughout the time of the experiment, and its period taken from time to time as might be found necessary.

1885	Number of Deflector	Approx. diar. of Deflector in cms.	Length of Deflector in cms.	Weight of Deflector in grammes	East and west Position.—Distance of centre of Deflector from the magnetometer needle in cms.	North and south Positions.—Distance of centre of Deflector from the magnetometer needle in cms.	Distance of the Scale from the magnetometer needle in cms.	Effective length of the Deflector in cms.	Magnetic moment per gramme of the Deflector in C.G.S. units	Horizontal intensity in C.G.S. units	Mean of each set of results
May 27	1	0·21	8·03	3·050	32·06	28·75	108·7	6·91	44·9	·1521	·1522
,, 27	2	0·21	8·05	3·063	32·06	28·75	108·7	7·10	58·5	·1524	
,, 28	3	0·21	8·05	3·075	32·06	28·75	108·7	6·31	54·1	·1521	
,, 29	4	0·21	8·05	3·067	32·06	28·75	108·7	7·11	52·3	·1522	
June 5	5	0·21	4·00	1·526	30·0	25·125	108·7	3·12	35·2	·1524	·1525
,, 5	6	0·21	3·99	1·522	30·0	25·125	108·7	3·72?	33·7	·1524	
,, 5	7	0·21	4·00	1·525	30·0	25·125	108·7	2·33	31·7	·1527	
,, 10	8	0·21	14·933	5·646	51·9	38·85	108·7	13·22	55·8	·1527	·1526
,, 11	9	0·21	15·030	5·727	51·9	38·85	108·7	12·82	64·3	·1525	
,, 11	10	0·21	15·021	5·666	51·9	38·85	108·7	13·58	54·5	·1527	
Aug. 21	10	0·20	10·01	2·318	35·0	30·0	128·9	9·14	71·0	·1526	·1526[1]
,, 21	12	0·20	10·01	2·336	35·0	30·0	128·9	9·14	62·7		
,, 26	11	0·20	10·01	2·318	35·0	30·0	128·9	8·91	71·0	·1527	
,, 26	12	0·20	10·01	2·336	35·0	30·0	128·9	8·98	62·7		
,, 31	13	0·20	10·00	2·318	35·0	30·0	128·9	9·14	70·0	·1526	
,, 31	14	0·20	10·005	2·336	35·0	30·0	128·9	9·14	61·8		

6. *On Atmospheric Electricity.*[2]

By Professor C. Michie Smith, *B.Sc.*, *F.R.S.E.*

The commonly accepted opinion, that during fine weather the air potential is always positive, is not accurate for Madras. There it is found that with a dry land wind (*i.e.*, a westerly wind) the potential of the air is usually negative during several hours of the day. In the early morning, and up to about 9 A.M., the potential is usually positive, then it becomes negative, reaching a maximum between 10 and 11 A.M., and continues negative till the sea breeze sets in in the

[1] Corrected to noon for diurnal variation.

[2] Published in full in *Phil. Mag.* Nov. 1885.

afternoon. During the prevalence of land winds there are frequent local showers, but these are evidently not the cause of the negative readings. Negative readings are never obtained in fine weather, except when the wind is westerly, and not even then, unless the ground is dry. A shower of rain, which cools the ground, makes the succeeding readings positive for some hours. A marked feature during the prevalence of land winds are the great clouds of dust which fill the air, and it seems probable that there is some connection between these dust clouds and the negative electrification of the air.

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7. *Molecular Distances in Galvanic Polarisation.*[1] *By* Professor J. LARMOR, *M.A.*

It has been shown, principally by Helmholtz ('Wissen. Abhand.' Vol. I. Galvanismus, and Faraday Lecture, 'Journal of the Chemical Society,' 1882), that polarisation involves a condensing action on the surface of the metallic electrodes. The particles, say of the cation, which exist in the electrolyte in a state of temporary dissociation, are drawn towards the cathode by the electromotive force till further approach is prevented by chemical forces. Thus along the surface of the cathode we obtain a sheet of positively charged cation molecules, which are in an equidistant arrangement on account of their mutual repulsion; and opposite to each on the material of the electrode there is the equal and opposite charge drawn there by electrostatic induction. This double sheet is equivalent to a condenser.

Kohlrausch and Helmholtz measured the charge required to produce a given polarisation difference of potential, and therefrom estimated the thickness of this double layer.

Lippmann ('Comptes Rendus,' 1882) determined the surface energy of the charge for unit area from the variation of the capillary constant of a mercury electrode; and thereby gained an estimate in agreement with the above.

We should expect that the capacity of the double layer per unit surface would remain constant until the distance between contiguous cation particles became of the same order as the thickness of the double layer, *i.e.*, until the contiguous particles began to feel one another's chemical forces, and be influenced thereby. An examination of Lippmann's results shows this constancy of capacity to a very close degree for a range of about a volt. We may, accordingly, conclude that with his acidulated water polarised to a volt the particles of the polarisation layer have just become so numerous as to be in chemical contact with one another. This leads to a third estimate of a molecular distance which we find to agree with the two former.

The first estimate is based on the absolute electrostatic measurement of the charge; the second on the measurement of a surface tension; the third on the absolute electro-chemical equivalent of the electrolyte. The complete agreement of three estimates founded on physical constants so various and of so different orders of magnitude, is strong evidence of the validity of this method of interpreting the phenomena of polarisation.

They are all in satisfactory agreement with the estimates of Sir W. Thomson and others from different considerations ('Nature' 1870, 'Appendix F, Thomson and Tait's Natural Philosophy,' part ii.), and give an average result of about one 10^{-10} metre, more or less.

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8. *On the Employment of Mance's Method for eliminating the Effects of Polarisation, to determine the Resistance of the Human Body. By* Dr. W. H. STONE, *M.A.*

The author commenced by stating that he had given a similar paper at the Southport meeting of the Association, in which it was noted that the electrical resistance of the human body was surprisingly less than that usually given, even by such authorities as Rosenthal, in Germany, and Dolbear, in America. He had

[1] See *Phil. Mag.* Nov. 1885.

shown that this was due to imperfect contact through the insulating skin. By immersing the extremities in saline solutions, and using large leaden electrodes, this initial error was eliminated, and a fair approximation to the real value obtained. But additional difficulties at once presented themselves; firstly, in that the living body acts as a secondary battery, and sets up very appreciable counter-electromotive force; secondly, that it has considerable electrostatic capacity, and acts to some extent as a condenser.

The former of these might be minimised by alternating momentary contacts with a reversing key, but, even thus, later readings were always somewhat higher than the earlier, giving a resistance compounded indefinitely of real resistance and polarisation. The use of alternate currents from a small induction coil on Kohlrausch's system, substituting a telephone for the galvanometer, an extremely elegant method, had occupied him for a year, but unfortunately it gives too low a result, probably from condenser action, and from the fact that a current rapidly reversed never actually traverses a very imperfect conductor like the human body, but only charges and discharges it in layers or segments.

Two opposite sources of error seem thus to be indicated, a condenser action spuriously lowering the reading, especially with alternate currents of high tension, and a polarisation action fallaciously raising it. The problem of ascertaining the amount of each of these was difficult. It had struck him, however, that the human body in many respects resembled a faulty submarine cable, in being at once a conductor, a condenser, and an electrolyte. He therefore, on the advice of Mr. Latimer Clark, adopted a method employed by Sir Henry Mance, on the Persian Gulf cables, and described before the Society of Telegraph Engineers, on May 8, 1884. It consisted in suddenly shifting the proportional coils of a specially constructed Wheatstone bridge (which was exhibited), and rapidly taking a fresh reading under the changed conditions. The values both of proportional coils and readings were then cross-equated so as to eliminate adventitious, and only retain intrinsic resistance. This method answered well, and gave results infinitely more concordant than any previously tried. For instance, two consecutive readings thus corrected gave 1,009 ohms and 1,007·8, a difference of less than one in 500, which was as near or nearer than could be expected in physiological electricity. He hoped thus to have overcome his first difficulty, and was endeavouring to meet those of measuring electrostatic capacity and opposite E. M. F. He already had roughly determined that the healthy body had a charging power as a secondary battery of about one volt or an ordinary Daniel cell, and he believed the chemical decomposition of tissue thus indicated was sometimes, especially in cases of rheumatic sciatica, the cause of the cure which frequently, indeed almost invariably, ensued.

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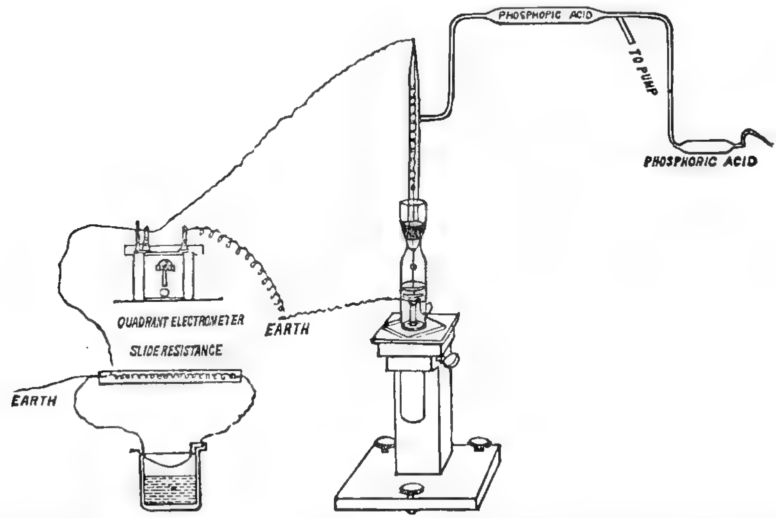
9. *On Contact Electricity in Common Air, Vacuum, and different Gases. By* J. T. Bottomley, *M.A., F.R.S.E.*

The discussion at the British Association meeting at Montreal last year on the seat of electromotive force in the voltaic cell, the paper of Professor O. Lodge which resulted from that discussion, and the subsequent discussion at the Society of Telegraph Engineers, must have brought forcibly before the minds of those interested in the subject the extremely unsatisfactory state of our experimental knowledge on some of the fundamental questions relating to contact electricity. Foremost among these, perhaps, is the question of the behaviour of various metals as to Volta contact effect in air and vacuum, and in gases different from common air. I have undertaken a series of experiments on this subject, and have already obtained some definite results; although the experiments which I have made up to this time are only to be considered as preliminary to a fuller inquiry.

The apparatus which I am using is shown in the diagram. The lower of the two plates to be experimented on is supported in the vacuum chamber by a small stand with a glass pillar, and the electrode from this plate passes through the side of the chamber, hermetically sealed into it. The upper plate is hung from the top

by a long platinum spiral, the upper end of which is also hermetically sealed into the glass. To the lower end of the spiral is attached a long hook, which carries the lower plate, and at the junction of the spiral with this hook there is a small globe of soft iron. It is by means of this small soft iron globe, and a magnet applied outside the tube, that the upper plate is lifted from the lower plate. The nature of the vacuum chamber and its connection to the pump will be readily



understood from the diagram. The final adjustment of distance between the two plates when at their nearest is done at the top of the tube by heating it and drawing out the glass carefully, or else letting it fall in till the adjustment is satisfactorily made. The branch tube on the right-hand side of the diagram, which is shown sealed off, is used for supplying gases to the apparatus. A small part only of the drying and purifying apparatus is shown in the diagram.

For determining the value of the Volta contact effect, I have used the quadrant electrometer and the compensation method of Sir William Thomson. The Daniell's cell and slide resistance and the connections are shown in the figure. The method is so well known that it need not be described here. It was given in 'Nature,' April 14, 1881, and has also been described in the paper of Professor O. Lodge, which was printed in the British Association Reports.

The plates which I have used are zinc and copper discs, a little larger than a shilling. Testing them first with full air-pressure, I found that the Volta contact difference was rather over 0·74 volt; which is as nearly as possible what has been found by previous experimenters, and by myself experimenting a few weeks ago with Sir William Thomson's old contact apparatus.

The air was then very carefully exhausted, the exhaustion being maintained for two days, and finally made exceedingly good with two and a half hours work at the pump just before testing. The pressure during the testing was not greater than, and was probably much less than $\frac{1}{523}$ mm. of mercury, or 2·5 M ($2\frac{1}{2}$ millionths of an atmosphere). The electrical test was then applied, and the value of the Volta contact effect was found to be *exactly the same as before,* a little over 0·74 volt. The final test, however, consisted in allowing the air to come back into the apparatus, and then testing electrically. This was done by breaking the point of the sealed tube to the right of the diagram; and as the air entered the electrometer test was rapidly applied. So far as the sensitiveness of the testing apparatus goes, there was absolutely no change in the Volta contact difference.

My experiments, therefore, are absolutely contradictory, so far as they have gone, to those of Dr. W. von Zahn, quoted by Professor Lodge, who experimented in a high vacuum and found the Volta effect to be diminished, and to be represented by a potential difference of only half a Daniell.

I have also experimented on hydrogen and oxygen gases in this apparatus in a way precisely similar to that described above. The chamber was very carefully exhausted, and the Volta contact effect tested with the electrometer. Hydrogen was then admitted, and while it was entering, which it was forced to do slowly, the electrical testing was repeated several times.

A second and a third exhaustion were made, and hydrogen admitted a second and a third time.

The same was subsequently done with oxygen, except that it was, of course, sufficient to admit the oxygen a single time. The result of my investigation, so far as it has gone, is that the Volta contact effect, so long as the plates are clean, is exactly the same in common air, in a high vacuum, in hydrogen at small and great pressure, and in oxygen. My apparatus, and the method of working during these experiments, was so sensitive that I should certainly have detected a variation of 1 per cent. in the value of the Volta contact effect, if such a variation had presented itself. To do away with all question as to the dependence of the Volta effect on 'ancient air sheets,' I propose to modify my apparatus by making the vacuum chamber much longer, and finally of combustion tubing. I shall then apply great heat to the plates while they are contained in a vacuum as high as I can command. If then there be any ancient air-sheets existing, they must either be driven off or else absorbed into the plates. If any gas be driven off, it will be removed by the pump. The plates will then be tested when they have perfectly cooled, and the value of the contact difference determined. That being done, the atmosphere air or some other gas will be admitted, and the contact difference will be again determined. The effect of the presence of the atmosphere or other gas will, I think we may safely suppose, be thus ascertained.

In conclusion, I have to express my indebtedness to Mr. J. Rennie, assistant to the Professor of Natural Philosophy in the University of Glasgow, for most valuable aid during my investigation.

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10. *On a Specimen of almost Unmagnetisable Steel.* *By* J. T. Bottomley, *M.A., F.R.S.E.*

The author has examined a specimen of steel presented to Sir William Thomson by Mr. R. R. Eadon, of the firm of Moses Eadon & Sons, Sheffield. This steel is made under Hadfield's patent, and contains 15 per cent. of manganese, and one side of the specimen bar has been polished, and shows that the steel is capable of taking a very high finish. The present specimen has probably a tensile strength of forty-five tons to the square inch. To test it magnetically, the bar was first touched with steel magnets, and such preliminary trials seemed to show that the magnets had not the slightest effect upon it. It was then placed between the poles of a powerful Rhumkorf electro-magnet, which was excited by forty large tray Daniells, arranged in fours for quantity and ten in series; and the process for magnetising which is always used in the Glasgow University laboratory, and which is very satisfactory, was proceeded with. It was very astonishing to find the bar of steel absolutely unaffected by the electro-magnet, so far as could be perceived by the hand.

After magnetisation the bar was carefully tested by the magnetometer method, a mirror magnetometer being used for the purpose. The weight of the bar is 192·09 grammes, its length is 14·29 centims, it is of square section, and is 1·5 centim thick. The effective length of the bar as a magnet was estimated at 10 centims. The magnetometer determination gave for the magnetic moment

$$\mu = 2{\cdot}55 \text{ c.g.s.}$$

Dividing by the weight of the bar we find for the magnetisation per gramme of this specimen of steel, 0·013 c.g.s.

To compare this with other specimens of steel we find in many specimens that magnetisation of 40, 50, or even 60 c.g.s. per gramme can be obtained. In some specimens as much as 90 or even 100 c.g.s. per gramme has been obtained.

P.S. The author has been informed that Dr. Hopkinson has already experi-

mented on steel containing manganese, and has obtained similar results. He has not, however, seen Dr. Hopkinson's figures, and is unable to compare his own results with them.

11. *On the Cooling of Wires in Air and in Vacuum.* *By* J. T. Bottomley, *M.A., F.R.S.E.*

This paper gave a brief account of recent experiments on radiation of heat from the surface of metallic wires in air and in vacuum. A preliminary paper on this subject was communicated to the British Association at its meeting last year. Since that time the arrangements for experimenting have been greatly improved, and further results have been obtained. The object is to determine in absolute measure the loss of heat from the surface of small wires of various materials, both uncovered and covered with various coatings, the wires being surrounded with different gases at various pressures down to the very lowest.

The chief experimenters on this subject in recent times have been Kundt and Warburg, and Mr. Crookes. My method of experimenting, which is very different from that of other experimenters, consists in passing a current of known strength through the wire under examination, and determining the increase in resistance of the wire due to heating of the currents when the wire has assumed a permanent temperature with the given current passing through it. When the temperature of the wire has become constant, the heat generated by the current (which can be calculated in absolute measure) must be equal to that emitted at the surface of the wire, plus that lost at the ends of the wire. The temperature of the wire at the moment is also ascertained from its resistance (as was done by Siemens in his experiments in resistance of platinum wire at different temperatures, 'Proc. R.S.' vol. xix. p. 443); and the emissivity of the surface of the wire can thus be determined in absolute measure.

My recent experiments have been directed to the determination of emissivities in very high vacuums. Using a Sprengel pump with five fall tubes, and a McLeod gauge of improved construction, due to Mr. C. H. Gimingham, I have obtained and measured a vacuum with air pressure as low as $\frac{1}{30}$ M (one thirty millionth of an atmosphere). The wire with which I am experimenting at present is a platinum wire half a metre long and 0·04 c.m. in diameter. It is contained in a glass tube about 0·6 c.m. internal diameter.

A table of emissibilities per metallic surface has not yet been completed, but one result obtained with a high vacuum may be quoted. On passing a current of 1·18 amperes through this wire with full air pressure, the permanent temperature obtained by the wire was 75° C., the temperature of the room at the time being 15·2 C. On exhausting down to $\frac{1}{19}$ M ($\frac{1}{19} \times 10^{-6}$ atmosphere) and passing the same current, the wire became heated to a good red heat.

FRIDAY, SEPTEMBER 11.

The following Papers and Reports were read:—

1. *On Kinetic Theories of Matter.* *By* Professor A. Crum Brown, *M.D., F.R.S.*

2. *On Kinetic Theories.* *By* Professor G. D. Liveing, *M.A., F.R.S.*

3. *On Thermal Effusion and the Limiting Pressure in Polarised Gas.* *By* G. Johnstone Stoney, *LL.D., F.R.S.*

4. *On a Law concerning Radiation. By* Professor SCHUSTER, *Ph.D., F.R.S.*

5. *On Boltzmann's Theorem. By* Professor W. M. HICKS, *M.A., F.R.S.*

It has always seemed to me that one of the strongest objections to Boltzmann's theorem lay in the supposition that the mean energy of any kind of vibration of any atom must be equal to that of translation in any direction, and therefore capable of unlimited increase. It is not difficult to conceive of systems where this cannot be true, as, for instance, a rigid spherical shell with a vortex ring inside. In this system the internal energy may be made to vary within certain limits, but cannot possibly be increased beyond a certain amount. The fact seems to be that Maxwell's theorem and Boltzmann's extension do not necessarily correspond to the actual state, but are only proved to give *possible* distributions of energy which are permanent. In any case, however, even if we assume the law of distribution of momenta given by them to be true, I can see no reason to justify us in assuming, either that all values of any momentum from $-\infty$ to $+\infty$ are possible, as is done in Watson's proof, or even that all values consistent with the equation of energy are possible, as is done in Maxwell's proof. If in Watson's proof all the non-existent states are left out of account, the *form* of solution is unaltered, but the energy will no longer be equally distributed amongst the co-ordinates. In this case, therefore, there is no difficulty in accounting for the ratio of the two specific heats in different cases, although it is not possible to predict it until the general constitution of the atom is known. Maxwell's proof takes account of the whole history of a molecule, and not merely of what happens at a collision as in Watson's. But it cannot be generally true that all states consistent with the equation of energy are possible. For instance there may be geometrical relations which prevent it, but which do not appear in that equation; as for example in a system of mutually attracting spheres. The equation of energy would permit of the infinite velocities due to an infinitely near approach of the centres of two spheres, a state which cannot exist owing to the finite size of the spheres. Another case is where the integrals of the equations of motion of the atom introduce relations between different momenta, as, for example, where part of the system consists of connected gyrostats.

6. *The Rate of Explosion of Hydrogen and Oxygen. By* H. B. DIXON, *M.A.*

The author has continued his experiments on the velocity of explosion of electrolytic gas. His results confirm those of Berthelot that the explosion is propagated at a constant velocity which is independent of the diameter of the tube. With a tube 100 metres long the mean of ten experiments gave a velocity of 2,819 metres per second, with a probable error of four metres. This velocity is in close agreement with the mean velocity of translation of the steam molecules produced in the reaction calculated on the supposition that all the heat produced is retained in the steam. The calculated velocity is 2,831 metres per second.

7. *Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements.*—See Reports, p. 31.

8. *Report on Electrical Theories. By* Professor J. J. THOMSON, *M.A., F.R.S.*—See Reports, p. 97.

9. *On Constant Gravitational Instruments for measuring Electric Currents and Potentials. By* Professor Sir W. THOMSON, *LL.D., F.R.S.*

These instruments, the author stated, were parts of two series of electric measuring instruments, for current and potential, which he was now working out. In the two current instruments—the milliamperemeter and the hecto-amperemeter—

the mode of effecting the measurement was founded on Faraday's law, according to which a ferro-magnetic mass placed in a variable magnetic field experiences forces tending to make it move from places of weaker to places of stronger force. The essential parts of the milliamperemeter are shown in the sketch diagram, fig. 1. It consists of an electro-magnetic coil, fixed with its axis vertical, and a little cylindrical mass of soft iron hung from one end of a light balanced lever so as to be free to move up and down in a circular arc, deviating but little in its middle and at its two ends from the axis of the coil.

The measurement is given by the deflections indicated on a scale by the end of

Fig. 1.

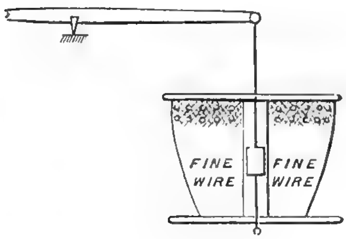
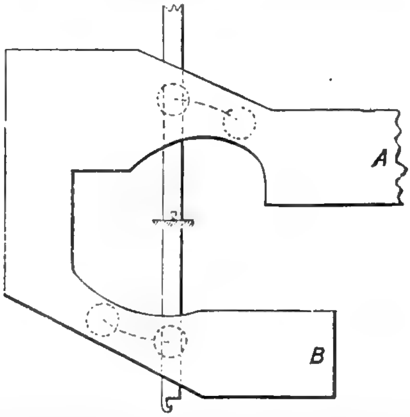


Fig. 2.



the balanced lever, when a weight of known amount is hung on the ring below the iron mass. To screen the iron from the effects of the earth's magnetism the coil is enclosed in an iron box.

In the hecto-amperemeter the variable magnetic field is obtained by a suitable disposition of the metallic conductor conveying the current to be measured. The conductor may be taken as consisting of two thick copper plates, shaped each according to the sketch, fig. 2, supported in a vertical position parallel to each other, say one centimetre apart, and metallically connected at the place indicated by B. At A is fixed a suitable electrode. The course of the current is therefore from A to B, and from B across to and through the other plate to the part of it corresponding to A, which forms the other electrode. In this way, two similarly varying magnetic fields are produced, and the balanced lever, capable of motion in a plane situated midway between the plates, carries two masses of iron, one in each field. In other respects, the instrument is similar to the milliamperemeter.

The electrometer consists of an air condenser with one of its plates capable of a to-and-fro motion so as to vary the capacity of the condenser.

The fixed brass plates are supported so as to be accurately parallel to each other and in metallic connection, while they are thoroughly insulated from the case of the instrument. The movable plate is of aluminium, and is supported in a vertical position on a knife edge; the plane of its motion being parallel to the fixed plates and situated midway between them. The upper end of this movable plate has a fine prolongation which serves as a pointer for indicating the deflections on the scale of the instrument, and at its lower end is fixed a knife edge having its length perpendicular to the plane in which the plate moves.

When the fixed and movable plates are connected respectively to two points of an electric circuit between which there exists a difference of potential, the movable plate tends to move so as to augment the electrostatic capacity of the instrument, and the magnitude of the force concerned in any measurement is proportional to the square of the difference of potential by which it is produced. In the use of the instrument this force of attraction is balanced by the horizontal component of a weight of any convenient amount hung on the knife edge at the bottom of the movable plate.

10. *On a method of multiplying Potential from a hundred to several thousand Volts. By* Professor Sir WILLIAM THOMSON, *LL.D., F.R.S.*

The method described by the author was to arrange in series a number n of condensers, where n is the number indicating the required multiplication. A terminal is connected to the junction between each pair of adjacent condensers. This series of $n+1$ terminals is conveniently placed so that by a suitable mechanism a pair of movable electrodes, between which a known difference of potentials exists, may be brought successively and repeatedly, at short intervals of time, into contact with each pair of adjacent terminals in the series, moving always in the same direction along them. In this way the difference of potentials established between the two end terminals of the series of condensers is n times the known difference of potentials between the movable electrodes.

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11. *On a form of Mercury Contact Commutator of Constant Resistance for use in adjusting Resistance Coils by Wheatstone's Bridge, and for other purposes. By* Professor J. VIRIAMU JONES.

The author was first led to consider commutators of the kind described by two needs: (1) In simple experiments on the induction of electric currents by the solution of a current in a magnetic field, it was desirable to substitute mercury contacts for the brass brass and copper copper contacts of the simple split ring commutator, and (2) for experiments on the resistance of electrolytes it is necessary to continue rapidly reversing the current without altering the resistance of the circuit.

The simple commutator with mercury contacts consists of two co-axal, parallel, and equal split rings of copper, the lines of split being parallel to one another, and the halves being cross-connected. The split rings are supported on ebonite discs. If it is desired to convert a continuous current into an alternating current without change of resistance in the circuit, it is only necessary to add to the above simple commutator two other (unsplit) rings of copper properly connected and turning in mercury cups communicating with the terminals of the part of the circuit in which the current is continuous.

If more rapid commutation is required, then by dividing the copper rings of the simple commutator into say six parts, and cross-connecting these, the current will be reversed six times in each revolution.

By means of eight discs, each carrying a copper ring divided into two parts, the lines of split in the first, fourth, fifth, and eighth, being all parallel and at right angles to the lines of split of the second, third, fifth, and sixth, which are also all parallel, we may by proper connections change the direction of the current through two independent coils, then interchange the coils, and again reverse the direction of the current through the coils in their new position. Such a commutator, it will be perceived, is of great utility in adjusting resistance coils by Wheatstone's bridge.

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12. *On Slide Resistance Coils with Mercury Contacts. By* Professor J. VIRIAMU JONES.

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13. *On the relative Merits of Iron and Copper Wire for Telegraph Lines. By* W. H. PREECE, *F.R.S.*

Copper is gradually replacing iron for aërial telegraphs, owing to its greater durability in the atmosphere; but its greater cost has led to the use of smaller-sized wires. This can be done without detriment to the economy of the line, for the resistance of copper, as compared with iron, varies very nearly inversely as its price per ton, and hence the cost per mile remains about the same. Hitherto only short lengths have been erected in smoky towns and through districts where

chemical industries filled the air with gases destructive to iron wires; but the Post Office Telegraph Department has recently erected a No. 14 copper wire, ·080 in. in diameter, weighing 100lb. per mile, all the way from London to Newcastle, 278·08 miles in length, and it became desirable to measure very accurately its electrical elements, so as to see if it possessed, as was anticipated, any marked advantage as a telegraph line over the galvanised iron wires hitherto used.

There were two series of experiments made. In the *first* series the relative electrical condition of the two kinds of wires was determined, and in the *second* series their relative rates of working.

The first series was divided into two parts, the one consisting of tests made from Bishop Auckland to Teams, near Newcastle, a distance of 30·235 miles on the north side, and to Pierce Bridge, a distance of 9·172 miles on the south side, and the other consisting of tests of a section of line between Pierce Bridge and Baldersby Cross Roads, 26·7 miles in length. The poles carried ten wires. The tests were made in dry and favourable weather by Messrs. Kempe and Eden.

The electrostatic capacity of an aërial line is known to vary as

$$\log \frac{4h}{d}$$

where h is the height of the wire above the ground, and d its diameter. Now, the average height of the copper wire on the sections between Bishop Auckland and Teams and between Pierce Bridge and Baldersby Cross Roads is 23 feet, and that of the iron wire (on a lower arm of the pole) 22 feet, their diameters being ·080 in. and ·171 in. respectively. We have, therefore, for copper wire

$$\log \frac{4h}{d} = \log \frac{4 \times 23 \times 12 \times 1000}{80} = 4{\cdot}1398791,$$

for iron wire

$$\log \frac{4h}{d} = \log \frac{4 \times 23 \times 12 \times 1000}{171} = 3{\cdot}7906678,$$

and

$$\frac{3{\cdot}7906678}{4{\cdot}1398791} = {\cdot}916 \text{ nearly,}$$

which makes the capacity of the copper wire to be $100 - 91{\cdot}6$, or 8·4 per cent. less than that of the iron wire. This result agrees pretty closely with the mean value of the differences of capacity obtained by actual measurements on these sections—viz., 9·1 per cent.

For the Bishop Auckland-Pierce Bridge section we have:—

For copper wire

$$\log \frac{4h}{d} = \log \frac{4 \times 21 \times 12 \times 1000}{80} = 4{\cdot}1003705.$$

For iron wire

$$\log \frac{4h}{d} = \log \frac{4 \times 20 \times 12 \times 1000}{171} = 3{\cdot}7492751$$

and

$$\frac{3{\cdot}7492751}{4{\cdot}1003705} = {\cdot}914$$

making the capacity of the copper wire to be $100 - 91{\cdot}4$, or 8·6 per cent. less than that of the iron, whilst the actual value was found to be 9·7 per cent. The differences between the calculated and the experimental values are probably due to the influence of trees, buildings, &c., which cannot be allowed for theoretically. These measurements were made when the other wires on the poles were left insulated. The effect of having all the other wires to earth when the capacity of any one wire was measured was very marked. Thus, on one wire the capacity was increased from ·352 to ·451 microfarad, or 22 per cent.

As regards the induction between wire and wire the effects obtained were very slight, though their actual value was determined with comparative accuracy.

The second series of experiments were conducted between London and New-

castle, and were designed, as stated above, to test the working efficiency of the copper wire as compared with iron wires. They were conducted by Messrs. Chapman and Eden.

Copper shows a very decided superiority over iron, the speeds being as follows:—

	Copper	Iron
Simplex working .	414 . .	345 words per minute.
Duplex " .	270 . .	237 " "

It is anticipated that the superiority of copper over iron indicated by these experiments will have a beneficial and economical influence on our telegraph system, and that its extended use will enable us not only to work better, but to dispense with intermediate repeaters in many cases where, on long lines, they are now necessary.

The most interesting point, however, in connection with these experiments is that they apparently prove that the superiority of copper is not simply due to its smaller electrostatic capacity and resistance, but that it is more susceptible to rapid changes of electric currents than iron; for when the resistance and capacity of the copper and iron wires were equalised by the insertion of resistance coils and condensers, the speed on the former was not thereby diminished. Possibly the magnetic susceptibility of the iron is the cause of this. The magnetisation of the iron acts as a kind of drag on the currents. It is well known that telephones always work better on copper than on iron wires, doubtless for the same reason.

These experiments also show the high speed of working that is now attained by the Post Office authorities with the Wheatstone automatic apparatus. The following table gives an interesting *résumé* of the different stages of the progress made, and its rate of growth:—

1877 .	. 80 words per minute.	1881 .	. 190 words per minute.
1878 .	. 100 " "	1882 .	. 200 " "
1879 .	. 130 " "	1883 .	. 250 " "
1880 .	. 170 " "	1884 .	. 350 " "

SATURDAY, SEPTEMBER 12.

The following Papers were read:—

1. *On Orthoptic Loci. By the* Rev. C. Taylor, *D.D.*

An *orthoptic point* with reference to a curve is a point at which it subtends a right angle, that is to say, it is the point of concourse of a pair of orthogonal tangents. The *orthoptic locus* of a curve is the locus of intersection of pairs of tangents drawn to it at right angles. It is proposed to determine the *order* of the orthoptic locus of a curve of given *class.*

The order of the locus is determined when its complete intersection with any straight line, for example the *line at infinity,* is known.

The tangents drawn from any point on the line at infinity are parallel, and in general cannot be regarded as including any finite angle. But the case is different with lines drawn from one of the circular points I or J.

Any two such lines, IO and IO′, may be regarded as including any angle whatsoever, since all the circles that can be drawn through any two points O and O′ pass through I.

The orthoptic locus of an ellipse (or hyperbola) is a circle, as De la Hire showed just two centuries ago (Paris, 1685). This may be demonstrated as follows:— From I (or J) one pair of tangents and one only can be drawn to the ellipse, and they may be regarded as intersecting at right angles. Hence I and J being single points on the locus and being its only points at infinity, the locus is a circle.

The orthoptic locus of the cardioid, a curve of the third class, is known to consist of a circle and a bicircular quartic, together making up a *tricircular sextic*. Such likewise must be the locus for a curve of the third class in general, since three tangents can be drawn to it from I (or J), and they may be regarded as intersecting two and two at right angles. Consequently I and J are threefold points on the locus: and they are its only points at infinity.

If the original curve be of class n, then from I (or J) n tangents can be drawn to it, and these can be taken in $n\frac{(n-1)}{2}$ ways in orthogonal pairs. This being therefore the order of each of the circular points on the orthoptic locus, the order of the locus is $n(n-1)$.

The order of the locus is apparently reduced when the original curve *touches the line at infinity*. Thus, in the parabola the line at infinity may be regarded as at right angles to the second tangent that can be drawn from any point upon it. Every such point therefore belongs to the locus, and the remainder of it when the line IJ is subtracted is a straight line not passing through the circular points, evidently the polar of the focus S, since SI (or SJ) is a tangent at right angles to itself. In like manner the reduction for a curve of class n which touches the line IJ in r points may be estimated.

By the same kind of argument it may be shown that if pairs of tangents be drawn to two curves of class m and class n respectively, each to each, their locus of intersection will be a curve of the order $2mn$, passing mn times through the circular points. The *pedal* of a curve of class n is therefore an n-circular $2n$-ic. That of an ellipse in general a bicircular quartic.

It remains to explain the apparent reduction of the order of the pedal with respect to a *focus*.

Taking for example the case of the ellipse, and eliminating between the equations:—

$$y-mx=\sqrt{(b^2+m^2a^2)}$$

and

$$my+x=\sqrt{(a^2-b^2)}$$

we have

$$(1+m^2)(x^2+y^2-a^2)=0$$

The factor $1+m^2$ equated to zero gives the directions of I and J, the tangents from which intersect in opposite pairs at the foci. The perpendicular from a focus S to the tangent SI is SI itself, which is accordingly a factor of the pedal, as likewise is SJ. But SI and SJ make up the *point-circle* at S. This factor corresponding to $1+m^2$ being rejected, the remainder of the pedal must be a circle, evidently that on the axis as diameter.

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2. *On the Reduction of Algebraical Determinants.* *By* W. H. L. Russell, *F.R.S.*

The following method, it will readily be seen, is applicable to all determinants in which the constituents of every column are rational and entire functions of (x). Consider the determinant:—

$$\begin{vmatrix} a_1+b_1x+c_1x^2+d_1x^3, & a_2+b_2x+c_2x^2+d_2x^3, & a_3+b_3x+c_3x^2+d_3x^3, \\ a_4+b_4x+c_4x^2+d_4x^3, & a_5+b_5x+c_5x^2+d_5x^3, & a_6+b_5x+c_6x^2+d_6x^3, \\ a_7+b_7x+c_7x^2+d_7x^3, & a_8+b_8x+c_8x^3+d_8x^3, & a_9+b_9x+c_9x^2+d_9x^3. \end{vmatrix}$$

Divide the first, second, and third rows by $a_1\ a_4\ a_7$ respectively, and subtract the first row from the second and third rows, and the determinant becomes

$$\begin{vmatrix} 1+b'_1x+c'_1x^2+d'_1x^3, & a'_2+b'_2x+c'_2x^2+d'_2x^3, & a'_3+b'_3x+c'_3x^2+d'_3x^3, \\ 0+b'_4x+c'_4x^2+d'_4x^3, & a'_5+b'_5x+c'_5x^2+d'_5x^3, & a'_6+b'_6x+c'_6x^2+d'_6x^3, \\ 0+b'_7x+c'_7x^2+d'_7x^3, & a'_8+b'_8x+c'_8x^2+d'_8x^3, & a'_9+b'_9x+c'_9x^2+d'_9x^3, \end{vmatrix}$$

that is:—

$$\begin{vmatrix} a'_5+b'_5x+c'_5x^2+d'_5x^3, & a'_6+b'_6x+c'_6x^2+d'_6x^3, \\ a'_8+b'_8x+c'_8x^2+d'_8x^3, & a'_9+b'_9x+c'_9x^2+d'_9x^3. \end{vmatrix}$$

$$+\mu x\begin{vmatrix} b'_1+c'_1x+d'_1x^2, & a'_2+b'_2x+c'_2x^2+d'_2x^3, & a'_3+b'_3x+c'_3x^2+d'_3x^3, \\ b'_4+c'_4x+d'_4x^2, & a'_5+b'_5x+c'_5x^2+d'_5x^3, & a'_6+b'_6x+c'_6x^2+d'_6x^3, \\ b'_7+c'_7x+d'_7x^2, & a'_8+b'_8x+c'_8x^2+d'_8x^3, & a'_9+b'_9x+c'_9x^2+d'_9x^3, \end{vmatrix}$$

Where μ does not involve (x): by repeating the process we obtain two more minors and the determinant:—

$$x^3\begin{vmatrix} p, & a'''_2+b'''_2x+c'''_2x^2+d'''_2x^3, & a'''_3+b'''_3x+c'''_3x^2+d'''_3x^3, \\ q, & a'''_5+b'''_5x+c'''_5x^2+d'''_5x^3, & a'''_6+b'''_6x+c'''_6x^2+d'''_6x^3, \\ r, & a'''_8+b'''_8x+c'''_8x^2+d'''_9x^3, & a'''_9+b'''_9x+c'''_9x^2+d'''_9x^3, \end{vmatrix}$$

so that the original determinant is resolved into the sum of six minors of the form:—

$$\begin{vmatrix} A_1+B_1x+C_1x^2+D_1x^3, & A_2+B_2x+C_2x^2+D_2x^3, \\ A_3+B_3x+C_3x^2+D_3x^3, & A_4+B_4x+C_4x^2+D_4x^3, \end{vmatrix}$$

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3. *Account of the Levelling Operations of the Great Trigonometrical Survey of India. By* Major A. W. BAIRD, *R.E., F.R.S.*—See Section E, p. 1123.

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4. *A Theorem relating to the Time-moduli of Dissipative Systems. By* Lord RAYLEIGH, *D.C.L., LL.D., F.R.S.*

In the proceedings of the Mathematical Society for June 1873, it is shown that the times of vibration of a conservative system fulfil a stationary condition, so that the time of vibration in any normal mode would remain unaltered, even though the system, by the application of suitable constraints, be made to vibrate in a mode slightly different. It is pretty evident that a similar theorem must obtain for the time-moduli of the normal modes of a dissipative system, but a formal statement may not be useless.

The class of systems referred to is that of which the mechanical properties depend upon *two* functions, one being the dissipation function F, and the other *either* the kinetic energy T, *or* the potential energy V. As examples of the first case may be mentioned, the subsidence of the small motion of a viscous fluid contained in a fixed envelope, and of free electric currents in a conductor. On the other hand, in the distribution of heat in a thermal conductor, or of electricity in a cable, the undissipated energy is usually regarded as potential. The argument is almost exactly the same whichever case be contemplated; to fix ideas we will take the former.

By suitable transformation the two quadratic functions T and F may be reduced to sums of squares of co-ordinates, and these co-ordinates are consequently called normal. Thus:—

$$T=\tfrac{1}{2}\,[1]\,\dot\phi^2, +\tfrac{1}{2}\,[2]\,\dot\phi_2{}^2+\ \ldots$$
$$F=\tfrac{1}{2}\,(1)\,\dot\phi^2, +\tfrac{1}{2}\,(2)\,\dot\phi_2{}^2+\ \ldots$$

in which all the coefficients [1] . . . (1) . . . are positive.

The normal modes are those represented by the separate variation of the co-ordinates, and the corresponding differential equations are of the form:—

$$[s]\ddot\phi_s+(s)\dot\phi_s=0,$$

whence

$$\phi_s=\mathrm{P}e^{-pt}$$

where

$$p=(s)/[s]$$

If τ_s be the time-modulus, the time in which the motion is diminished in the ratio of $e:1$, $\tau_s=p^{-1}$.

Suppose now that by suitable constraints an arbitrary type of motion is imposed upon the system, so that $\phi_1=A_1\theta$, $\phi_2=A_2\theta$, . . . where A_1, A_2 &c. are given (real) coefficients. Then

$$T=\{\tfrac{1}{2}[1]A_1{}^2+\tfrac{1}{2}[2]A_2{}^2+\ \ldots\ \}\dot\theta^2$$
$$F=\{\tfrac{1}{2}(1)A_1{}^2+\tfrac{1}{2}(2)A_2{}^2+\ \ldots\ \}\dot\theta^2;$$

and the equation of motion

$$\frac{d}{dt}\frac{dT}{d\theta\cdot}\Big) + \frac{dF}{d\theta\cdot} = 0$$

gives as the solution $\theta \propto e^{-pt}$, whence

$$p = \frac{(1)A_1^2 + (2)A_2^2 + \ . \ .}{[1]A_1^2 + [2]A_2^2 + \ . \ .}.$$

It is evident that the value of p (and therefore of τ) is stationary when all but one of the coefficients A_1, A_2, &c., vanish, that is when the type coincides with one of those natural to the system.

From this theorem corollaries may be drawn as from the corresponding theorem for times of vibration. The greatest time-modulus can only be reduced by the application of constraint, and where the normal mode is difficult of calculation a good approximation to the greatest time-modulus may be had from a hypothetical type chosen so as not to deviate too widely from the real one. Any increase in T or diminution in F as a function of the co-ordinates entails in general an augmentation in all the time-moduli. In the case of free electric currents, already referred to as an example, this augmentation of time-moduli would result from the approximation of iron (treated as a non-conductor), or from an improvement (however local) in conductivity.

5. *On a new Polariser devised by Mr. Ahrens.* *By* Professor SILVANUS P. THOMPSON, *D.Sc.*

This prism consists of a tetragonal block of calc-spar, the square ends of which are principal planes of section of the crystal; the axis of symmetry of the prism being at right angles to the crystallographic axis. It is divided by two planes making an angle of about 36° with one another; their intersecting line lying across the middle of one of the end faces. These two planes divide the prism into three wedges which are united together by Canada balsam. The polarised field of vision has about 28° of angular aperture. The line of junction which traverses the end face is quite imperceptible when the prism is used as a polariser, though it interferes slightly with the field when the prism is used as an analyser. In the writer's opinion it is the best polariser hitherto designed.

6. *On a simple Modification of the Nicol Prism giving Wider Angle of Field.* *By* Professor SILVANUS P. THOMPSON, *D.Sc.*

This modification consists in reversing the obliquity of slope of the end-faces, making them incline about 5° instead of 45° with the crystallographic axis, and in cutting the crystal across in such a plane that the balsam film makes 89° with the new end faces, or about 94° with the crystallographic axis. This 'reversed' prism may have, externally, exactly the same form as the ordinary Nicol prism if cut from a longer piece of spar. If cut from a piece of the same proportions as an ordinary Nicol prism, the new prism will be somewhat shorter; but will have a slightly wider field. The 2 'reversed' prisms presented to the section have angular fields of 32° and 37° respectively. That of the ordinary Nicol is about 25° 30′. This method of construction may be looked upon as a compromise between the methods of Hartnack and of Nicol. It combines most of the advantages of the former with the cheapness of the latter.

7. *On some of the Laws which regulate the Sequence of Mean Temperature and Rainfall in the Climate of London.* *By* H. COURTENAY FOX, *M.R.C.S.*

The materials used in preparing this paper are the monthly temperature and rainfall for the Royal Observatory, Greenwich, from 1815 to the present time. They form a series of carefully recorded facts extending over the long period of

seventy years. In order to make practical use of this large mass of material, it was arranged in the following manner:—Taking out first all the Januaries, then the Februaries, and so on, I arranged each month, not in chronological order, but in the order, first, of its mean temperature, and afterwards of its rainfall. The same thing was also done for each meteorological season (winter consisting of the three months, December to February, and the other seasons in order).

In accordance with the principle which I had the pleasure of explaining to the British Association in 1879, and which is described at page 277 of the Report for that year, I divided each of these arranged lists as nearly as possible into five equal sections. Those referring to temperature are termed respectively, very cold, cold, average, warm, and very warm, and those referring to rainfall are named, very dry, dry, average, wet, very wet. We have thus a fair division of this long series of years, as regards the important characters of warmth and moisture. This simple arrangement is of the greatest utility in enabling us to generalise upon the mass of facts that have accumulated to our hand.

Taking out first all those months that were 'very cold,' there is no difficulty in writing down against them, in order, the character as regards mean temperature and rainfall of the months that came next after, and in saying how many of these latter were very cold, how many were cold, and so on, through the several sections of temperature and rainfall. Then, to ascertain the influence of high temperature, or of very dry or rainy weather, we take out all those months that were very warm, or very dry, or very wet, and proceed in the same manner. Supposing, for example, that we wish to inquire in what way great warmth in January affects the following month. We take all the instances (fifteen in number) within the last seventy years in which January was 'very warm.' Obviously there must be fifteen Februaries to be examined. We find that three of these were 'very cold,' none were 'cold,' five were of 'average' temperature, two were 'warm,' and five were 'very warm.' Therefore, as regards the *temperature* of February it is safest to say that the result is *indefinite*, because the three very cold and the five very warm ones too nearly balance each other to enable us to assert that there is a distinct tendency toward either side. But as regards the *rainfall* of these same Februaries, we find that seven of them were very dry, one was dry, two were average, three more were wet, and the remaining two were very wet. These facts exhibit a strong tendency for a very warm January to be followed by a dry February. Out of fifteen cases, seven Februaries were very dry against two that were very wet. The *probability*, therefore, of a very dry rather than a very rainy February may be conveniently expressed by the formula—7 to 2 out of 15.

Proceeding in the manner thus briefly indicated, it is remarkable what a harvest of interesting results promises to reward the inquirer. It is, indeed, surprising in how many cases the warmth or moisture of one month or season is discovered to be influenced by some unsuspected law of association with the month or season which it succeeds.

Omitting all those results which are of an ambiguous or indefinite character, I would venture to state the following definite propositions:—

1. A very cold spring tends to be followed by a cold and wet summer. The probability of a very cold summer is decidedly strong, being 6 to none out of 15,[1] and that for a very wet one is 5 to 1 out of 15.

2. A very cold summer tends to be followed by a cold autumn, the probability being 6 to 1 out of 14.

3. Very warm summers are prone to be succeeded by warm autumns, 5 to 1 out of 14.

So much for the influence of the seasons on those which come directly after them. Except in these three instances I perceive no definite law. Now let us see the apparent effect of one month upon another following it:—

4. In seven out of the twelve months we find that *very low* temperatures tend to be prolonged into the succeeding months. Thus, a very cold January gives a likelihood of a cold February, the probability being 4 to 1 out of 14; a very cold

[1] That is to say, of fifteen very cold springs, six were followed by very cold summers, and *none* by a very warm one.

April has a strong tendency to be followed by a cold May, 6 to none out of 13; a very cold June conduces to a cold July, 6 to 2 out of 13; and a very cold July to a cold August, 5 to none out of 13. A very cold August gives a remarkably strong probability of a cold September, 7 to none out of 14; a very cold September is succeeded by a cold October in the smaller ratio of 4 to 1 out of 13; and a very cold December tends to be followed by a cold January, 6 to 1 out of 14. It is noticeable that in three of these months, April, July, and August, the influence of cold is so strong that the facts were *without marked exception.*

In the other five months of the year I find no evidence that low temperature definitely affects the succeeding months. Meanwhile it is interesting to observe that of the seven which do show influence four are consecutive, namely, June, July, August, and September, the hottest four months of the year.

5. A very warm June has a strong probability to be succeeded by a warm July, 7 to none out of 13; and a very warm July by a warm August, 7 to none out of 14. A very warm August tends to be followed by a warm and wet September, the probability for each one of these events being identical, namely, 5 to none out of 15. It will be noticed that this proposition applies to the three consecutive summer months, and that the facts were without any marked exception.

6. The rainfall sequence of consecutive months and seasons appears to observe no definite rule, except in one striking case, which is as follows:—A very dry August is apt to be followed by a wet September, 7 to 1 out of 16. *Nowhere else* do we find a distinct tendency for a month or season to be of *opposite* character as regards warmth or moisture to that which it succeeds.

In addition to the foregoing, there are some instances in which the *temperature* of certain months appears to be related to antecedent conditions of *rainfall,* and *vice versâ.* Thus:—

7. In two months of the year the fact of their being *dry* is strongly followed by warmth in the next month. Thus a very dry June has a strong tendency for a warm July, 5 to none out of 15; and a very dry July for a warm August, 6 to none out of 13.

8. On the other hand, in three months of the year *abundant rain* gives likelihood of a warm month to follow. Thus a very wet January is followed by a warm February, 7 to 1 out of 13; a very wet March by a warm April, 4 to none out of 11; and a very wet April by a warm May, 5 to 1 out of 13.

9. The contrary of this occurs in two months—a very wet May being strongly followed by a cold June, 6 to none out of 14; and a very wet July by a cold August, 5 to none out of 13.

10. A very warm January is likely to be succeeded by a dry February, 7 to 2 out of 15.

It may naturally occur to ask—all these being instances in which a month or season is looked at in *one* character only—What are the results when they are examined with relation to the *combinations* of temperature and moisture? Do their characters, as warm and wet, cold and dry, warm and dry, cold and wet, show a tendency to influence the months following? We cannot so fully answer this question, because, in proportion as we define the character, we lessen the area of the observation. At the same time there are a few results that it may be worth while to adduce.

11. *Warm and Wet.*—If November be of this character (which has happened five times in the past 70 years), December will tend to be wet, 2 to none out of 5; so also a very warm and very wet December is likely to be followed by a wet January, 4 to 1 out of 6. But in January the same combination gives a probability of a warm February, 4 to 1 out of 8.

12. *Cold and Dry.*—If November have this character, the following December has a slight tendency to be dry, 2 to none out of 6. But a very cold and very dry December gives likelihood of a cold January, 3 to none out of 6.

13. *Warm and Dry.*—In two months this combination is strongly followed by a continuance of warm weather. Thus a very warm and very dry June is succeeded by a warm July; or if July be of this description, the ensuing August tends to be warm, the probability in either case being 4 to none out of 7. On the other

hand, a very warm and very dry August is prone to be succeeded by a wet September, 4 to none out of 7. In each of these cases the actual probability is four-sevenths, but the value of this fact is much strengthened by there being *no case* of the opposite.

14. *Cold and Wet.*—If July have this character the next month will generally be a cold one, 3 to none out of 5. So, likewise, a very cold and very wet August tends to be followed by a cold September, 3 to none out of 5.

15. With regard to the meteorological seasons, there is only one case in which the combination of extremes of temperature and moisture in one season seems to definitely influence the following one. A very cold and very wet summer is usually succeeded by a cold autumn. The facts in this case, although few in number, give evidence of a remarkably strong probability, being 3 to none out of 4.

In conclusion, I beg to offer these results, so far as they go, with some confidence, obtained as they are from the *purely numerical treatment* of a long course of carefully recorded facts, whilst they are utterly free from any bias derived from theory. Let it be freely acknowledged that they take the rank only of *empirical* laws, which may some day be knit together by cautious induction to form a part of the future science of meteorology.

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8. *Notes upon the Rotational Period of the Earth and Revolution Period of the Moon deduced from the Nebular Hypothesis of Laplace. By* W. F. Stanley, *F.G.S., F.R.M.S.*

This paper was in part a defence of the nebular hypothesis of Laplace (last note 'Système du Monde') in opposition to a modification of it proposed by Mr. G. H. Darwin ('Phil. Trans.' 1879, p. 536) as regards the present and former velocities of motions of the earth and moon. The author proposed a theory by which the relative velocities of an earth and moon might be deduced from consideration of the early nebulous conditions. Thus where the nebulous system of the earth was contracting by loss of heat, and the tangential velocity of the exterior parts of it exceeded the centralising action of gravitation, so that it was possible for a satellite system to become detached, there must necessarily be a plane of equilibrium of the particles surrounding the earth where they would be equally solicited by the earth and by its satellite, and this would be the plane of separation of the system. After the separation, the tangential velocities of the separate parts would give the final velocity of the central mass when these parts had condensed to form it. Thus taking the earth and the moon, or their original nebular systems by the simple formula $e : m :: d^2 : d_1^2$, where e and m are earth and moon, and d and d_1 the respective masses. The attraction being directly proportional to the mass, and inversely as the square of the distance, we find by this formula in taking the separate densities and distances of the earth and moon, that the earth at its point of separation where a particle would be in equilibrium would form at first a nebulous globe of 212,347 miles radius. The tangential velocity of the equatorial surface of this globe, assuming it moved at the present rate of the moon, of one revolution in about $27\frac{1}{3}$ of our days, would be a sidereal tangential velocity of 1,334,213 miles in this period. The present velocity of the earth's equator taken for the same period is 679,305 miles, or only about half this. If we assume the *density* of matter of the nebulous system which formed the earth diminished directly as the square of the distance from the centre, then upon condensation the equatorial surface of the present globe should have the final velocity of its original nebulous equator immediately after its separation from the moon, supposing the system acting entirely without friction. But during the formation of the present globe, the matter condensed upon the central mass impressing its momentum of higher tangential velocity upon this mass would cause the centre of the system to have higher radial velocity than the exterior parts, and as the exterior of the system would still be nebulous matter offering considerable resistance to the central mass moving at higher radial velocity, this motion would be necessarily frictional, causing a relative loss of velocity in the central mass which would be developed into heat. It is also

probable that a liquid nucleus was already formed at the period of separation of the earth and moon systems, so that the tangential motion of the exterior nebulous mass surrounding it must be taken into the relative inertia of the denser centre. Therefore the present velocity of the earth's rotation becomes quite rational, allowing this deduction from its former nebular velocity, assuming this has remained a constant on the conditions proposed, according to the hypothesis of Laplace.

9. *On a Galvanic Battery.* *By* C. J. BURNETT.

MONDAY, SEPTEMBER 14.

The following Reports and Papers were read:—

1. *Report of the Committee on Standards of White Light.*

See Reports, p. 61.

2. *Photometry with the Pentane Standard.* *By* A. VERNON HARCOURT, *M.A., F.R.S.*

At Southport two years ago the author exhibited and described a lamp fed with a mixture of gaseous pentane and air which gave constantly when its flame was maintained at a height of $2\frac{1}{2}$ inches (63·5 m.m.) the light of an average sperm candle. Various improvements in the lamp have been made since that date. The narrow tube whose diameter determines the quality of the gas burnt forms the through-way of the plug of a stopcock at the bottom of the siphon, and thus its freedom from obstruction can be verified at any moment. A metal cylinder containing an arrangement of rack and pinion by which the wire above the flame can be adjusted to any desired height has been placed round the burner, and upon this when the flame is exposed to draughts stands a glass chimney partially closed above and below by a perforated metal plate. Thus protected, the flame of the lamp is much steadier than the flame of the candle.

The loss of light due to a thin cylindrical chimney of clear glass has been found by placing such chimneys round a small glow lamp, through which a constant current was passed. It amounts to about 1 per cent. A greater absorption of light, amounting to 6 per cent., occurred with an equally clear chimney of thicker glass. By adjustment of the size and number of the holes in the plates below and above the chimney, the height and brightness of the flame can be made the same when the chimney is used and when it is not.

The relation between the height of the flame of pentane gas burning from a gas-holder and the light emitted has been determined. From a height of 71·5 m.m., at which the flame gives the light of 1·2 candle, down to a height of 35·5 m.m., at which the light is that of 0·3 candle, every millimetre of height corresponds to a light of ·025 or $\frac{1}{40}$ of a candle. Measurements of the light of gas and oil flames ranging from 900 to 2,500 candles were made at a distance of 50 feet in the photometric gallery at the S. Foreland, the pentane burner being fixed at a distance of one or $\sqrt{2}$ foot from the illuminated paper, by adjusting the height of the flame till equal illumination was obtained, bringing down the platinum wire till it touched the tip of the flame, lowering or extinguishing the flame, and reading on a scale of millimetres the height of the wire above the burner.

For testing lighthouse burners with a Bunsen photometer the pentane lamp was used either at its normal height of 63·5 m.m. or, when distant lights had to be measured, with a shorter flame. The relation between the height of flame and light of the lamp has been determined for a range of 30 m.m.

Lastly, the effect of variations of atmospheric pressure upon the pentane flame

has been determined. To give constant light the height of the flame must be increased or diminished by ·2 m.m. for every ·1 inch of barometric height below or above 30 inches. The height of the flame is thus inversely proportional to the atmospheric pressure, as though the flame were a visible cone of gas of constant base. It is found that the height of the flame varies directly with the volume of gas passing to the burner. Recent observations on Ben Nevis show a less rate of variation for a difference of 4 inches of the barometer.

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3. *On a Photometer made with Translucent Prisms. By* J. Joly, *B.E.*

When two pieces of a translucent substance such as paraffin are placed in contact along a plane face and illuminated by sources of light placed on opposite sides of this plane and viewed in this plane, they do not appear equally bright unless the illumination by each source is equal. This may be used as a very sensitive test of equality of illumination, and so as a photometer. It has this advantage over both shadow and Bunsen's photometers, that the illuminated surfaces to be compared are in absolute contact along the line of contact of the two pieces of paraffin.

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4. *Report of the Committee for reducing and tabulating the Tidal Observations in the English Channel, made with the Dover Tide-gauge; and for connecting them with Observations made on the French coast.*—See Reports, p. 60.

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5. *Seventeenth Report of the Committee on Underground Temperature.* See Reports, p. 93.

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6. *Fifth Report of the Committee on Meteoric Dust.*—See Reports, p. 34.

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7. *A Tabular Statement of the Dates at which, and the Localities where, Pumice or Volcanic Dust was seen in the Indian Ocean in* 1883–84. *By* Charles Meldrum, *F.R.S.*—See Reports, p. 773.

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8. *Report of the Committee for co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the Year* 1861.—See Reports, p. 60.

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9. *Daily Synoptic Charts of the Indian Ocean. By* Charles Meldrum, *F.R.S.*

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10. *Report of the Committee appointed to co-operate with the Scottish Meteorological Society in making Meteorological Observations on Ben Nevis.*—See Reports, p. 90.

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11. *On the Meteorology of Ben Nevis. By* Alexander Buchan.

The advantages possessed by Ben Nevis as a first-class meteorological observatory are these: it is the highest mountain in the British Islands, rising to 4,406 feet; its summit is in horizontal distance little more than four miles from a sea level station at Fort William, and it is situated in the track of Atlantic storms which exercise so preponderating an influence on the weather of Europe, especially in autumn and winter. Its advantages are thus unique, and observations made there are of the highest interest and value in meteorology.

In establishing this national observatory, the object sought to be attained was a knowledge of atmospheric changes and disturbances such as would lead to a juster conception of the great movements of the atmosphere, and of the weather preceding, accompanying, and following these movements. From the knowledge thus gained, and from the Ben Nevis daily observations themselves, the value of forecasts of the weather of the British Islands will, it is believed, be much enhanced.

The importance attached to the Ben Nevis Observatory as contributing aid in framing weather forecasts for the British Islands was soon apparent in discussing the observations in some of their relations to the weather changes of North-Western Europe. The occurrence of remarkable differences from the normals was disclosed in the vertical distribution of the temperature, pressure, and humidity of the atmosphere between the top of Ben Nevis and the sea level at Fort William. As the discussion proceeded it became more and more apparent that these differences gradually grouped themselves into separate classes according to the different types of weather which either prevailed at the time or occurred soon after.

A series of large inquiries thus open up which will lead to important scientific and practical results. These inquiries are, it is unnecessary to say, among the most difficult in physics, and for their satisfactory investigation the directors have thought it essential in the first place to investigate as completely as possible the meteorology of the top of the mountain and of Fort William at its base. This being done, the bearing of the Ben Nevis observations on the weather of the British Islands can be more satisfactorily investigated, particularly the bearing of the observations on the coming weather—an investigation now being prosecuted.

With regard to the climatology of Ben Nevis, reference is made to the Report submitted to this Meeting (see page 90), and to the previous Reports. A large number of other observations have been made and entered in '*the log*' of the observatory which yet remain undiscussed. These embrace optical observations, the state of the sky, and other eye-observations, which cannot be conveniently entered in the daily weather sheet, but which are of the greatest importance in the meteorology of Ben Nevis, particularly in investigating weather changes.

The greatest interest attaches to departures from the normals occurring so repeatedly, of which the thermometric and hygrometric are the most striking. Thus the state of complete saturation of the atmosphere which may be regarded as the characteristic of the weather of the Ben frequently gives way, often quite suddenly, and the air becomes dry, frequently intensely dry, the sky singularly clear, and the temperature rises rapidly, resulting in the relative humidity often falling to 30, or on rarer occasions below 20.

These recurring periods of intense dryness and heat do not occur at any of the stations of the Scottish Meteorological Society at lower levels; and from Mr. Wragge's observations made in 1882 at the eight stations established that year on the slopes of Ben Nevis from sea level to the top, it was shown that the weather conditions of this type are confined to the highest part of the mountains. Heavy rains appear always to accompany this weather, occurring in some neighbouring region. These are the essential characteristics of the foehn; and its frequent occurrence on Ben Nevis which stands isolated above all the hills around it, leads to the conclusion that it is also of not infrequent occurrence in all parts of Europe, at heights in the atmosphere of about 4,400 feet and upwards.

If this be so, consequences of the greatest importance follow. Instances have occurred when the temperature on Ben Nevis has been from 5° to 8° higher than in the vicinity near sea level, and as the normal temperature of Ben Nevis is 16°·3 lower than at Fort William, it follows that the temperature sometimes rises fully 20° above the normal difference. Now as regards the aerial stratum from sea level to 4,406 feet high, this manner of distribution of temperature with height will not be productive of any violent movements. But it is quite otherwise for heights greater than Ben Nevis, where it is evident temperature will fall with height at a rate very greatly exceeding the normal. It is probable that it is from the conditions of unstable equilibrium here indicated that whirlwinds and the more dangerous gusts which occur during storms have their origin.

A comparison of the winds on the top of Ben Nevis with the surface winds shows that sometimes both are within the same cyclonic system or of the same anticyclonic system overspreading that part of Europe at the time. In such cases the direction is nearly always different, and so far as the investigation has been carried it appears that the observed differences give an indication as to whether the coming storm will pass to the north or to the south of Ben Nevis.

Sometimes, however, while the surface winds are part of a cyclone, the winds on Ben Nevis are part of an anticyclone, and *vice versâ*; or putting it in other words, the manner of the distribution of atmospheric pressure at sea level over this region of North-Western Europe is quite different from what obtains over the same region at the height of 4,406 feet. It is this peculiarity in the winds and atmospheric pressure of Ben Nevis, due to its height and proximity to the central paths of the Atlantic storms, which will give to the observations an additional value in framing daily weather forecasts for the British Islands.

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12. *On some Results of Observations with kitewire-suspended Anemometers up to* 1,300 *feet above ground, or* 1,800 *feet above sea-level, in* 1883–85. *By* E. DOUGLAS ARCHIBALD.

The author began by relating that he had, since the Montreal meeting of the Association, made twenty-five fresh observations, and as these embraced records at altitudes reaching to 1,300 feet above the ground, or 1,800 feet above the sea, he hoped the results from them, as well as fifteen of the former observations combined, might be considered sufficiently numerous and valuable to merit a short discussion.

In the discussion the observations were divided into six groups, according to altitude, and the exponent for each observation in the formula $\frac{V}{v} = \left(\frac{H}{h}\right)^x$ being calculated, the means were taken for each group, with the following results:

TABLE I.

Group	Mean height of upper instrument above ground	Mean height of lower instrument above ground	Mean velocity of upper instrument	Mean velocity of lower instrument	Mean of both	Mean value of x
	H	h	V	v		
(1)	250	102	1,617	1,174	1,395	·372
(2)	322	128	2,232	1,679	1,955	·307
(3)	407	179	1,705	1,385	1,545	·275
(4)	549	252	2,107	1,773	1,940	·237
(5)	795	481	2,192	1,957	2,074	·250
(6)	1,095	767	2,236	2,096	2,166	·194

From which it is manifest (as well as from the individual observations) that *while the velocity always increases with the height above the ground as far as* 1,800 *feet above sea-level, the ratio of the increase measured by the exponent x progressively diminishes.*[1]

As the station itself is 500 feet above sea-level, the motion of the air at some height above the surface should correspond more or less with that at an equivalent height above the sea over an open sea-level plain. Where this actually is exactly the case is difficult to determine, but assuming that it is approximately the case at the mean level of group 6, or 931 feet above the ground, and adding 400 feet to both heights, we get $x = 0{\cdot}26$, which is nearly identical with the value already

[1] The exceptional case of group 5 being due to the inclusion in that group of an abnormally large value of x corresponding to an equally abnormally small velocity.

determined by the author as the value of the exponent in the formula $\frac{V}{v} = \left(\frac{H}{h}\right)^x$ which best accords with the results of Dr. Vettin's cloud observations over Berlin extending from 1,600 to 25,000 feet above sea-level ('Nature,' vol. xxv. p. 506), and the result shows not only that the observations of the author agree generally with those of Dr. Vettin, but also that beyond a certain height the exponent becomes nearly constant. The author finds, apart from height, that the values of the exponent, or in other words the ratio of the increase of the velocity with the height, is affected principally by four factors: (1) the mean velocity of the two heights; (2) the hour of the day; (3) the direction of the wind; and (4) the time of year.

On comparing the exponents for each group with each of these factors in turn variations appear of a periodic character, which in some cases are difficult to exhibit independently, owing to chance arrangements of the other factors affecting the results co-directionally. In the first two cases, however, the results can be shown to be independent of the other factors, and lead to the enunciation of the following laws:—

1. Above the first 160 feet from the ground, the exponent generally decreases with an increase of velocity, and *vice versâ*. Below the first 160 feet this law is apparently reversed, owing probably to undue sheltering of the lower instrument by surrounding objects.

2. When the exponents are arranged for different hours of the day, for heights above 160 feet and up to 1,300 feet above the ground, the exponents in all the four upper groups show a uniform increase from a minimum value about 2 or 3 P.M. to a maximum about 7 or 8 P.M. Below 160 feet the first two groups show some signs of a contrary variation, which may admit of an explanation similar to that for the preceding law.

This second law is in complete agreement with Dr. Köpvpen's theory of the diurnal period in the velocity of wind and other casual observations of the author, but requires more morning observations to confirm it.

The other laws of which indications have been observed are a maximum value of the exponent for winds from a westerly quarter and a minimum for those from an easterly quarter. Also a maximum value of x in October falling to a minimum in the winter and rising again to a maximum in spring and early summer, but these are more involved by the co-existence of the other factors.

The last law, if found to be confirmed, might be due in part to the changes in terrestrial friction due to the falling of the leaf in winter.

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13. *On the Measurement of the Movements of the Ground, with reference to proposed Earthquake Observations on Ben Nevis. By* Professor J. A. Ewing, *B.Sc., F.R.S.E.*

Measurements of earth movements are of two distinct types. In one type the thing measured is the displacement, or one or more components of the displacement, of a point on the earth's surface. For this purpose the mechanical problem is to obtain a steady point to be used as an origin of reference, and this is effected by making use of the resistance which a mass opposes to any change of motion. This may be called the *inertia method* of observing earth movements. It is applicable to ordinary earthquakes, and also to the more minute earth tremors, which would pass unnoticed if instrumental means of detecting their presence were not employed. The steady point is to be obtained by suspending a heavy mass (with one, two, or three degrees of freedom) in such a manner that its equilibrium is very nearly neutral. Any moderately sudden displacement of the ground in the direction in which the mass has freedom to move leaves the mass almost undisturbed, and the displacement of the ground is therefore easily measured or recorded by a suitable autographic arrangement, which must be so designed as to introduce exceedingly little friction.

The second type of measurements is that in which the thing measured is any

change in the inclination of the surface of the ground relatively to the vertical. Movements of this class have been examined by d'Abbadie and Plantamour, and also by G. H. and H. Darwin, who have given the results of their observations to the British Association in two Reports on the Lunar Disturbance of Gravity (1882-3). Perhaps the most convenient name for these movements is earth-tiltings. They are measured by what may be called the *equilibrium method.* A pendulum suspended in a viscous fluid is employed to show by its equilibrium position the true direction of the vertical, and that is compared with the direction of a line which is fixed relatively to the surface of the ground; or, instead of a pendulum, a dish of mercury or a pair of spirit-levels are employed to define a truly horizontal surface, and the tilting of the earth's surface relatively to that is observed.

This method is practicable only when the displacements of the surface have so great a vertical amplitude in comparison with their horizontal wave-length that the slope of the wave is sensible; and further, only when the changes of slope occur slowly enough to put the inertia of the pendulum or fluid out of account. On the other hand, the inertia method is applicable only when the displacements have so short a period in comparison with their amplitude that the acceleration of the ground during the greater part of the motion is large relatively to the frictional resistance of the suspended mass. Between ordinary earthquakes and tremors on the one hand, capable of observation by the inertia method, and slow earth-tiltings on the other, capable of observation by the equilibrium method, it is at least possible that there may lie many movements not reducible to either type. For example, if successive upheaval and subsidence of small amplitude were to occur with a very long horizontal wave-length, and with a period of say one or two minutes or more, it would be practically impossible even to detect its existence by either of the methods named, unless by chance it were repeated several times with uniform period in the presence of a very frictionless vibrator whose free period happened to agree nearly with the period of the disturbance; even then no measurement of its amount could be made. We are in fact forced to classify earth-movements under the two heads which have been named—not because there is any necessary discontinuity between the two, but because they must be treated by two entirely distinct modes of observation.

For the measurement of palpable earthquakes by the inertia method the writer has devised many instruments which have been successfully applied to the registration of Japanese earthquakes, and which are described in a memoir on earthquake measurement published in 1883 by the University of Tokio. He has not attempted in any case to give the astatically suspended mass three degrees of freedom, and nothing would be gained by doing so. An instrument with two degrees of freedom is now exhibited to the Association. It consists of an ordinary pendulum coupled with an inverted pendulum in such a manner that the two bobs move together in any horizontal direction. This combination of a stable with an unstable mass can be adjusted to give any desired degree of astaticism. In practice it is convenient to allow the joint mass to have a free period of from five to ten seconds—the period of ordinary earthquake waves being much less than this. A long and light lever pivoted to the frame of the instrument at one point and to the steady mass at another forms a registering index, by which a magnified trace of the earth's horizontal movement is deposited on a fixed plate of smoked glass with the least possible friction.

In another instrument two separate components of horizontal motion are determined each by a horizontal pendulum tilted slightly forwards to give a small degree of stability, and furnished with a multiplying pointer. In this instrument the pointers trace the successive movements of the earth on a plate of smoked glass, which is kept revolving uniformly by clockwork. The velocity and acceleration of the movements are deducible from the records. This is the standard form of seismograph employed by the writer; and to make the information it gives complete, another instrument for registering on the same plate the vertical motion of the ground is added.

The vertical motion seismograph is a horizontal lever, supported on a horizontal fixed axis, and carrying at one end a heavy mass. A spring, attached to a fixed

point above, holds up the lever by pulling on a point near the fulcrum. To make the mass nearly astatic the point at which the spring's pull is applied is situated below the horizontal line of the lever, so that when the spring, by (say) being lengthened, pulls with more force, the point of application moves nearer the fulcrum, and the moment of the pull remains very nearly equal to the moment of the weight.

Apart from the registration of palpable earthquakes, the inertia method is to be applied to the minute earth tremors which have been observed in Italy by Bertelli and Rossi, and which are probably to be found wherever and whenever one searches for them with sufficient care. But in dealing with them no mechanical means of recording can well be applied on account of its friction, and a still more frictionless method of suspending the heavy mass is desirable. The writer prefers for this purpose a mode of astatic suspension (of which a model was exhibited) based on Tchebicheff's straight line motion; and to detect the movement of the ground he observes, by a microscope fixed rigidly to the frame of the machine, the displacement of the frame with respect to the suspended mass. This is Bertelli's method, except for the substitution of a nearly astatic mass for the stable mass used by him—namely, the bob of a short pendulum—which, of course, gives a misleading magnification of certain vibrations.

The writer was recently requested by the directors of the Ben Nevis Observatory to design seismometers for use there, and obtained a Government grant for their construction. The equipment at Ben Nevis will include recording seismographs and a micro-seismometer of the kind just described. To measure slow earth-tiltings an instrument is being constructed in which a modification (due to Wolf) of d'Abbadie's arrangement (described in Professor Darwin's Reports) is followed. Light from a lamp travels some twenty feet horizontally to a mirror inclined at 45 degrees to the horizon. It passes vertically down through a lens which brings the rays into parallelism. They strike two reflecting surfaces—one the surface of a basin of mercury, the other a plane mirror very rigidly fixed to the rock. The rays come back to form two images near the source, and any relative displacement of the two images is measured by a micrometer microscope. In the choice and design of this instrument the writer has to acknowledge much assistance from Professor G. H. Darwin. This apparatus, like the others, was intended for Ben Nevis, but a visit to the observatory there has convinced the writer that to use it on that site, and in the atmosphere which prevails on the top, would be a matter of extreme difficulty, and that, in the first instance at least, observations should be made with it on lower ground.

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14. *On the supposed Change of Climate in the British Isles within recent years. By* THOMAS HEATH, *B.A.*

This note gives the result of an examination of the Meteorological Tables published by the Registrar-General of Births, Marriages, &c., in Scotland, and shows that there has been no material alteration in the mean temperature, either of all Scotland or of six stations whose records have been separately examined; but that there has been a decided increase in the amount of rainfall within recent years, which increase seems to exhibit itself more particularly on the eastern coast.

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15. *On Malvern, Queen of Inland Health Resorts, and on improved Hygrometric Observations. By* Professor C. PIAZZI SMYTH, *F.R.S.E.*

The conditions for health resorts so often include useful requirements for scientific observing stations, that the author hoped the identification, chiefly by hygrometrical observations, of a remarkably favourable example of the former, might be interesting to a British Association meeting.

Having first carried on several weeks' observing in a low level region of the Midland Counties, he then removed to Malvern Hills with the same instruments, and immediately obtained more than twice the amount of depression of the wet below the dry bulb thermometer, as ordinarily observed at the first station.

The reasons for this remarkable dryness he then discusses, and adds to what has been already advanced by local medical men, the elevation of Malvern above the *stratus*—fog level of the low country, the effect of rising above which he compares, though on a far smaller scale, to rising above the north-east wind's cloud level on the Peak of Teneriffe.

Several other circumstances are then detailed, which all tend to enhance the mean temperature, check the variations or range of temperature, and decrease the strength of the winds at Malvern, combining altogether to produce the most genial and healthy atmosphere yet ascertained in Great Britain.

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16. *The Annual Rainfall of the British Islands.* *By* ALEXANDER BUCHAN.

As regards the British Islands, the greatest differences in local climates arise from differences in the rainfall. If the climate of Skye be compared with that of the coasts of the Moray Firth, in no month will the mean temperatures be found to differ so much as $2^{\circ}\cdot 0$, and for several months of the year they are nearly identical. But the annual rainfall of Skye rises to, and in many places exceeds 100 inches; whereas from the mouth of the Spey to Tain, the rainfall is little more than a fourth part of that amount; and this difference in the rainfall, with the clear skies and strong sunshine which accompany it, renders the southern shores of the Moray Firth one of the earliest and finest grain-producing districts of Scotland, whereas Skye is one of the latest and poorest grain-producing districts. Hence the paramount importance of the rainfall in the climatology of a country.

The temperatures of comparatively few places are required, in order to draw, with approximate correctness, the lines of mean atmospheric pressure and temperature for any particular region. But with the rainfall it is very different, this being, of meteorological data, the most difficult to represent cartographically, and there is no other way to arrive at a tolerable approximation to the average rainfall of a district than by numerous rain-observing stations. This inquiry, the results of which are represented on the map exhibited, is based on observations of the rainfall made at 1,080 stations in England and Wales, 547 in Scotland, and 213 in Ireland—in all 1,840; and while it cannot be said that any district is overstocked with rain-gauges, large districts remain wholly, or at least very imperfectly, represented.

The period which has been selected for this inquiry is the twenty-four years extending from 1860 to 1883, it being only in 1860 that fairly adequate data for the whole of the British Islands began to be available by the appearance of Symons' 'British Rainfall.' In Mr. Symons' energetic hands, aided for some years by grants from the British Association, the stations for observation of the rainfall, and the publication, have increased year by year, till in 1884 the stations number nearly 2,600, and the publication occupies 242 pages. While the returns published by the Meteorological Societies of England and Scotland, and returns from other sources have been utilised, it is mainly on Mr. Symons' invaluable annuals that this inquiry is based.

The methods of discussion employed, and the average annual rainfall of the different stations, are detailed at length in the 'Journal of the Scottish Meteorological Society,' recently published.

The distribution of the rainfall for the twenty-four years over the British Islands is shown by six shadings indicating the districts where the annual rainfall does not exceed 25 inches; is from 25 to 30 inches; from 30 to 40 inches; from 40 to 60 inches; from 60 to 80 inches; and lastly above 80 inches.

The regions of heaviest rainfall, marked off by an average of 80 inches or upwards annually, are four—Skye and a large portion of the mainland to the south-east as far as Luss on Loch Lomond; the greater part of the Lake district; a long strip including the more mountainous part of North Wales; and the mountainous district in the south-east of Wales.

The West Highlands present the most extensive region of heaviest rainfall in the British Islands. The mountain masses along whose slopes the rainfall is pre-

cipitated offer a practically unbroken face of highlands to the rain-bringing winds of the Atlantic. Further, these mountain masses present innumerabls lochs and valleys directly in the course of these winds, up which therefore the winds are borne, and being cooled as they ascend, pour down those deluges of rain which deeply trench the sides of the mountains in the lines of their watercourses. The heaviest rainfall in Scotland, 128·50 inches, is at Glencroe in this district.

On the other hand, the smallest rainfall, varying from about 22·50 inches to 25·00 inches, overspreads a large portion of the south-east of England, extending from the Humber to the estuary of the Thames, exclusive of the higher grouuds of Lincoln and Norfolk, where the rainfall rises above 25 inches. To this is to be added a small patch in the valley of the Thames, from Kew to Marlow. In every other part of the British Islands the rainfall exceeds 25 inches.

The districts characterised by rainfalls intermediate between these extremes were then referred to, and it was pointed out that everywhere the key to the distribution of the rainfall is the direction of the rain-bringing winds in their relation to the physical configuration of the surface. Of this law or method of the distribution, the rainfall over the south-western counties of England is one of the best examples. Some of the other more striking illustrations are the Bristol Channel, which secures an increased rainfall for a large portion of central England; the Solway Firth, together with the mountainous regions on each side of the entrance to it, in their influence on the singular distribution of the rainfall of the south of Scotland and north of England adjoining; and the mountains of North Wales, with the estuary of the Dee, in their relations to the rainfall of a large portion of England lying to the east and north-east.

As regards the rainfall of the twenty-four years from 1860 to 1883, the most noteworthy feature is the comparatively large average amount for the second half of the period over nearly the whole of the British Islands. The excess is most marked over the more strictly eastern districts, the means of the 12 years ending 1883 being generally from 5 to 10 per cent. greater than the means for the twenty-four years.

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17. *Remarkable Occurrence during the Thunderstorm of August* 6, 1885 *at Albrighton. By* J. Bedford Elwell.

St. Cuthbert's, my residence, is situated at Albrighton, ten miles from Wolverhampton, with which it is connected by telephone. The house has a lightning protector twenty-five years old. The telephone wire very improperly makes earth on this conductor.

The storm was at its height about half-past eight in the evening, and we had just retired to the drawing-room, there being only a single lamp left alight in the dining-room, in the centre of the corona. The telephone-bell was sounding with every flash of lightning, when suddenly a report like a rifle shot was heard in the hall, and at the same instant the servants in the dining-room were plunged into darkness by the lamp in the corona flashing up and then going out. (Another lamp was immediately put in, showing the leads were not injured.) Also at the same moment the telephone wires were both fused. The wire sometimes used to connect the telephone with the drawing-room was also fused, and through it the lightning tried to make earth (or *vice versâ*) all over the electric light system, succeeding in one place, in a bedroom over the entrance hall, where a bell-pull was close to one of the leads. The current struck across—showing an E.M.F. of many thousand volts—and fused the bell wire. None of the lead cut-outs were fused on any of the wires.

On examining the burnt lamp in the dining-room, it was found to be so blackened that (although it was perfectly clear and bright the moment before, and, being a 48 volt Swan lamp, could not be overrun from 24 cells) it was with difficulty that the filament could be seen. It was burnt off at *both ends* where the platinum wire joined, *and lay entire* in the bottom of the globe. A few globules of melted glass or platinum were also rolling about within the globe.

The glass globe has become a beautiful mirror by the fine particles of platinum that have been projected against it.

N.B.—A *separate earth-plate* has since been put to the telephone, so that nothing of the kind can again happen.

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18. *On a supposed Periodicity of the Cyclones of the Indian Ocean south of the Equator. By* CHARLES MELDRUM, *F.R.S.*

In papers printed in the Reports for 1872, 1873, 1874, and 1876, I endeavoured to show that there were grounds for supposing that the cyclones of the Indian Ocean south of the equator increased in number, extent, and intensity from a minimum in one year to a maximum in another, and then decreased to a minimum, the period or cycle apparently corresponding with the eleven-year period of solar activity.

From the data given in the last of those papers (Report for 1876, page 267) it would appear that from 1856 to 1875, the years of minimum cyclone-activity were 1856 and 1867, and the years of maximum activity 1861 and 1872, but that the results for each of those years did not differ much from the results for the year immediately preceding or following it, the variation near the turning-points being small.

Before giving a brief outline of the results which have been obtained since 1875, it may be well to mention that the sources of information were the same as in former years. Two clerks were constantly occupied in tabulating the meteorological observations contained in the log-books of vessels that arrived in the harbour of Port Louis from different places. The number of days' observations tabulated in each year, that is, observations extending over twenty-four hours, and made in different parts of the Ocean, was as follows:—

Years	Days' Observations	Years	Days' Observations
1876	17,017	1881	16,473
1877	17,005	1882	15,089
1878	17,050	1883	16,930
1879	15,889	1884	15,697
1880	17,306		

The tables give an average of forty-six observations of twenty-four hours each for every day of the nine years over the frequented parts of the Ocean.

All details and reports respecting hurricanes, storms, or gales, were recorded in separate registers.

For each day on which there was a gale in any part of the Ocean between the equator and the parallel of 34° S. a chart was prepared, showing as nearly as possible the positions of the vessels, the direction and force of the wind &c. at a certain hour, viz., noon on the meridian of 60° E.

From these synoptic charts, the details given from hour to hour in the log-books, and all the information obtained from other sources, the positions of the centres of cyclones at noon on each day were determined, and the tracks laid down on separate charts.

Nine Cyclone-Track Charts have thus been prepared, since 1875, namely, one for each of the years 1876–84.

These Track-Charts, together with the twenty that had previously been prepared for the years 1856–75 show, as far as has yet been ascertained, the tracks of the cyclones of the Indian Ocean south of the equator in each of the years 1856–84, and the tracks for the years 1848–55 are nearly ready.

With respect to the period 1876–84, the *areas* of the cyclones and the *distances* traversed have not yet been determined, but upon the whole the *number* and *duration* of the cyclones decreased to a minimum in 1880, and then increased till, in 1884, they were more than double of what they were in 1880.

From the accompanying Track-Charts for the eleven years 1856, 1857, 1860, 1861, 1867, 1868, 1871, 1872, 1879, 1880, and 1884, it will be seen that the number

and duration of the cyclones of 1856 and 1857 were much less than those of the cyclones of 1860 and 1861: that the number and duration of the cyclones of 1867 and 1868 were much less than those of 1860 and 1861 on the one hand, and also than those of 1871 and 1872 on the other; and that the number and duration of the cyclones of 1879 and 1880 were much less than those of the cyclones of 1871, 1872, and 1884.

It would appear, however, that in 1884 there was less cyclone-activity than in 1861 and 1872.

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19. *A new Wind Vane or Anemoscope, specially designed for the use of Meteorologists.* *By* G. M. WHIPPLE, *B.Sc., F.R.A.S.*

The author described a modification of the ordinary wind vane which serves to render its indications more certain when read from a distance.

He permanently attaches the letters N.E.S.W. to the vane and carries them round with it. A fixed pointer is suitably placed beside the vane or beneath it, and the observer merely looks at the letters and determines the direction of the wind from their position with reference to the pointer.[1]

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20. *On the Third Magnetic Survey of Scotland.* *By* Professor T. E. THORPE, *F.R.S., and* A. W. RÜCKER, *F.R.S.*

At the last meeting of the British Association held in Aberdeen, Professor Balfour Stewart presented the Report of the Observations made in connection with the Magnetic Survey of Scotland in the years 1857 and 1858. This Survey was undertaken at the request of the Association by the late Mr. Welsh, of the Kew Observatory, and the report is published in the account of the Society's Proceedings for 1859. Mr. Welsh's observations constitute the second magnetic survey of Scotland, the results of the first survey having been recorded by the late Sir Edward Sabine in the 'Report of the British Association for 1838.'

In a 'Note on the Irregularities in Magnetic Inclination on the West Coast of Scotland,' published in the Proceedings of the Royal Society for Nov. 15, 1883, we drew attention to the fact that the present time was very opportune for a new magnetic survey of Scotland as part of a general survey of the British Islands. 'More than twenty-five years,' it was remarked, 'have elapsed since Mr. Welsh made his survey, and this was separated by an interval of twenty-one years from that which we owe to the joint labours of Sir Edward Sabine, Sir James Ross, and Mr. Fox. The instruments and methods of observation in 1858 were greatly superior to those in 1836–7, and hence a new survey, made during the approaching period of minimum sun-spot disturbance and on stations selected with careful reference to their geological character, would undoubtedly afford far more accurate data as to the absolute value of the magnetic elements, and as to the extent of secular change in this part of the world, than we at present possess.'

As the accounts of the previous surveys were published in the Reports of the British Association, we may perhaps be allowed to take this opportunity of intimating to the members that we have during this and the preceding summer made the necessary observations for the survey suggested in the above remarks. A determination of the magnetic elements, that is of inclination, declination, and force, has been made at fifty stations. The great increase in the facilities for travelling in Scotland since 1857–8 has placed us at a considerable advantage as compared with Mr. Welsh for reaching various places at which observations were desirable. The greater number of the coast stations were visited in a yacht belonging to one of us; in this way we were able to observe under more favourable conditions as to choice of situation and duration of stay, than if we had been dependent upon the ordinary steamboat service.

The following is a list of the stations:—

[1] For illustration, see *Quart. Jl. Roy. Met. Soc.* vol. xi. p. 64.

Berwick-on-Tweed (W.).	Crianlarich.	Soa.
Hawick.	Oban (W.).	Canna.
Dumfries (W.).	Kerrara.	Loch Boisdale.
Stranraer (W.).	Iona.	Loch Maddy.
Ayr (W.).	Coll.	Stornoway (W.).
Carstairs (W.).	Tiree.	Callernish (W.).
Edinburgh (W.).	Loch Aylort.	Gairloch.
Glasgow (W.).	Bannavie (W.).	Loch Inver (W.).
Fairlie.	Dalwhinnie (W.).	Loch Eriboll.
Campbelltown (W.).	Ballater.	Thurso (W.).
Port Askeg (Islay) (W.).	Aberdeen (W.).	Wick (W.).
Tarbert (Loch Fyne).	Banff (W.).	Golspie (W.).
Strachur.	Elgin (W.).	Lairg.
Stirling.	Boat of Garten.	Stromness (W.).
Dundee.	Inverness (W.).	Kirkwall (W.).
Pitlochrie (W.).	Fort Augustus (W.).	Lerwick (W.).
Crieff.	Kyle Akin (W.).	

W. signifies a station also observed at by Mr. Welsh in 1857 or 1858. The stations are distributed as uniformly as possible over the whole area of Scotland, and they have been chosen with the view of repeating the measurements at as many as possible of the positions selected by Mr. Welsh, and, at the same time, of avoiding as far as might be regions of great local disturbance. At stations where Mr. Welsh's notes gave the requisite details we have observed when possible on the exact site he occupied. At new stations we have been careful to select positions which are likely to remain open, so that future observations can be made there.

Some of the declinations determined by Mr. Welsh on the west coast were discarded when his results were published by Professor Stewart, as the mirror of the magnetometer was found to have been out of adjustment on several occasions. Owing to the improvements made in the Kew Unifilar since the time of the last survey, the liability to error from this source is practically obviated: it is now possible to ascertain readily whether the mirror is properly set and, if necessary, to readjust it, before making the solar azimuth observations. With the view, however, of still further minimising the errors due to the axis of the mirror being either not parallel to its plane, or not perpendicular to the line of collimation of the telescope, our observations of the transits have been made by alternate reversals of the axles in its bearing and by back and front observations of the sun.

The accuracy of the determinations of solar azimuth, and hence of the declination, has been greatly increased by the circumstance that we were able to make frequent comparisons of our chronometers with the time signals sent daily from Greenwich at 10 A.M. and 1 P.M. along the telegraphic system of England and Scotland. We have to thank Mr. Cunynghame, the Director-General of Telegraphs at Edinburgh, and Messrs. Tansley and Redford, Superintendents of the Glasgow and Ayr districts respectively, for the facilities afforded us in this part of our work. We are also much indebted to the postmasters at the various places visited for the readiness with which they arranged for the transmission or reception of the signals.

Our Magnetometer (No. 60 Elliott) and Dip Circle (No. 74 Dover) were compared with the Kew instruments by observations taken by ourselves and by Mr. T. W. Baker at the Kew Observatory. Our thanks are due to the Kew Committee of the Royal Society and to Mr. G. W. Whipple for the assistance thus rendered.

The actual work of the survey was prefaced by an inquiry as to the nature and extent of the influence exerted by the great centres of local disturbance at various parts along the west coast of Scotland. With a view of obtaining information on this matter we selected the island of Mull, the geological characters of which have been very fully described by Professor Judd, and which, as Mr. Welsh's determinations show, exerts a highly disturbing influence. The observations were made in the summer of 1883, and are published in the 'Proceedings of the Royal Society' for 1883–4. They serve to indicate within what limits such centres of local disturbance may be approached without affecting the general direction of the

isoclinals. The survey was begun in the summer of 1884, and was continued during the spring, summer, and autumn of the present year. We have been assisted in some of our later observations by Mr. A. P. Laurie, of King's College, Cambridge, who was good enough to undertake the measurement of the dips at a number of the inland stations. Our best thanks are due to Mr. Laurie for the valuable help thus rendered.

It is hardly possible for us as yet to say anything about the general results of the survey, as the observations are only partially reduced. We trust to be able to complete the calculations without delay. We venture, however, to hope that the statement that all the necessary observations for what now constitutes the third Magnetic Survey of Scotland have been taken, may not be without interest for the members of the British Association.

TUESDAY, SEPTEMBER 15.

The following Reports and Papers were read:—

1. *Report of the Committee for considering the best means of Comparing and Reducing Magnetic Observations.*—See Reports, p. 65.

2. *Report of the Committee for considering the best methods of recording the direct Intensity of Solar Radiation.*—See Reports, p. 156.

3. *On a means of obtaining constant known Temperatures. By* Professor W. Ramsay, *Ph.D., and* Sydney Young, *D.Sc.*

This method, which has involved the determination of the true vapour-pressures of numerous substances, with help of mercurial, air, and vapour-pressure thermometers, is published in full in the 'Trans. Chem. Soc.,' Sept., 1885.

4. *On certain facts in Thermodynamics. By* Professor W. Ramsay, *Ph.D., and* Sydney Young, *D.Sc.*

This paper has reference to the equation

$$\frac{L}{s_1 - s_2} = \frac{dp}{dt}\frac{T}{J}$$

While Dr. Ramsay discovered in 1877 that $\frac{L}{s_1 - s_2}$ at the same pressure is approximately constant for all liquids for which there exist data, the correctness of the data and assumptions on which the statement is based was open to question. Hence the investigation was unpublished until a relation in some degree connected with this was rediscovered by Mr. Trouton, 'Phil. Mag.' 1884, p. 54. Since then, Dr. Young noticed that the value of $\frac{dp}{dt}\frac{T}{J}$ at the same pressure is an approximate constant for all liquids, and as the data in this case are much more reliable than in the former, it has been thought desirable to publish both researches under one title.

The first law is:—*The amounts of heat required to produce unit increase of volume in the passage from the liquid to the gaseous state at the boiling-point under normal pressure are approximately constant for all bodies; or* $\frac{L}{s_1 - s_2} = C$.

The second law is:—*If the amounts of heat required to produce unit increase of volume in the passage from the liquid to the gaseous state be compared at different pressures for any two bodies, then the ratio of this amount at the boiling-point under*

a pressure p_1 to the amount at another pressure p_2 is approximately constant for all liquids; *or*

$$\frac{L}{s_1 - s_2} \text{ at } p_1 \text{ bears a constant proportion to—}$$

$$\frac{L}{s_1 - s_2} \text{ at } p_2 \text{ for all liquids and probably for all solids.}$$

It has also been noticed as a corollary from the first law that the internal and total work bear an approximately constant ratio to each other for any one pressure, whatever the liquid.

In considering the second part of the equation, the following relations have been noticed:—

If a curve be constructed to represent the relation of temperature to pressure for any liquid, and if tangents be drawn to touch the curve at various points corresponding to certain temperatures, these tangents will give the rate of increase of pressure per unit rise of temperature, in other words, the value $\frac{dp}{dt}$ for those temperatures.

If we construct curves for a number of substances, and determine the value of $\frac{dp}{dt}$ for each of them at the same temperature, it is clear that the values obtained will differ widely, and will be greater for volatile substances than for those which are less volatile. But if we determine the values of $\frac{dp}{dt}$ not at the same temperature, but at the same pressure, the conditions under which the comparison is made will be more similar, and the resulting values may be expected to differ much less. In the calculation of the vapour pressures of a number of substances for each degree between certain limits of pressure, it became evident that at any given pressure the rate of increase was generally, though not always, greater for the volatile substances than for the less volatile.

A closer study of the matter led to the following generalisations:—

1. The products of the rate of increase of pressure per unit difference of temperature into the absolute temperature $\frac{dp}{dt}.T$ are approximately the same for all stable substances at the same pressure, but the differences are real and are not due to errors of experiment or calculation.

2. The rate of increase of this value $\frac{dp}{dt}.T$ with rise of pressure is the same for all stable bodies, at any rate for pressures between 150 and 2,000 mms., while for alcohol and water it is the same for all pressures between 100 and 20,000 mms.

3. In the case of certain substances nearly related to each other, such as bromo- and chlorobenzene, or ethyl bromide and chloride, the ratio of the absolute temperatures of the related bodies at any given pressure is a constant.

Complete paper to be found in 'Phil. Mag.,' December 1885.

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5. *Report on Optical Theories.* *By* R. T. Glazebrook, *M.A., F.R.S.*

See Reports, p. 157.

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6. *On a Point in the Theory of Double Refraction.* *By* R. T. Glazebrook, *M.A., F.R.S.*

The author suggested that the theory of double refraction given by Lord Rayleigh, in which the ether is supposed to have an effective density different in different directions, might be modified so as to agree with Fresnel's theory if it be not necessary to assume that the ether offers an infinite resistance to compression, but only that as compared with its rigidity, its incompressibility is very great, and

further, that in a crystal the light vibrations are normal to the ray, not to the wave normal, as was pointed out by Boussinesq, and referred to by Ketteler in some of his papers.

7. *Exhibition of a Mechanical Model illustrating some properties of the Ether.* *By* G. F. FITZGERALD, *F.R.S.*

8. *On the Constitution of the Luminiferous Ether on the Vortex Atom Theory.* *By* Professor W. M. HICKS, *M.A., F.R.S.*

The simple incompressible fluid necessary on the vortex atom theory is quite incapable of transmitting vibrations similar to those of light. The author has therefore considered the possibility of transmitting waves through a medium which consists of this fluid modified so as to contain small vortex rings closely packed together. The rings are supposed composed of the same material as the rest of the fluid, to be very small compared with the wave length, and at distances from one another also small compared with the wave length. Their motion of translation is also taken to be so comparatively slow that very many waves can pass over any one before it has much changed its position. Such a medium would probably act as a fluid for larger motions.

The vibration in the wave front may be (1) swinging, such as a ring oscillating on a diameter, (2) transversal vibrations of the ring, (3) vibrations normal to the plane of the rings, (4) apertural vibrations. Of these (3) seems to be impossible. If r be the radius of the rings, l the distances of their planes, μ their cyclic constant, and v the velocity of translation, the author found
for

$$(1)\ v \propto \frac{\mu}{l}\left(\frac{r}{l}\right)^4$$

for

$$(2)\ v \propto \frac{\mu}{l}\left(\frac{r}{l}\right)^2$$

whilst for (4) in case of rings arranged parallel to a wave front,

$$v \propto \frac{\mu r^4 l^2}{(l^2+4r^2)^{\frac{5}{2}}}.$$

9. *On an improved Apparatus for Christiansen's Experiment.*[1] *By* Lord RAYLEIGH, *D.C.L., LL.D., F.R.S.*

10. *Optical Comparison of Methods for observing small Rotations.*[2] *By* Lord RAYLEIGH, *D.C.L., LL.D., F.R.S.*

11. *On the Accuracy of Focus necessary for sensibly perfect Definition.*[3] *By* Lord RAYLEIGH, *D.C.L., LL.D., F.R.S.*

12. *On Electro-Optic Action of a charged Franklin's Plate.*[4] *By* J. KERR, *LL.D.*

The experiments described in this paper were carried out by the author in 1882, and he has now made them known in view of certain statements made by M. Wiedemann in his 'Die Lehre von der Electricität,' vol. ii.; particularly where

[1] Published in the *Phil. Mag.*, Oct. 1885. [2] *Ibid.*
[3] *Ibid.* [4] *Ibid.*

he says that there appears to be no electro-optic double refraction in the case of a uniformly charged Franklin's plate. The results obtained were shown by the author to prove that electrostatically strained glass acts in the polariscope as if compressed along the lines of electric force, *and this always, whether the electric field is uniform or not.*

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13. *On Magnetic Double Circular Refraction.*[1] *By* DE WITT B. BRACE, *Ph.D.*

The main object of the investigation has been to determine whether the refractive index of a medium under magnetic stress experiences a change for circularly polarised light when the direction of propagation is that of the lines of force.

In connection with the investigation, several important equations have been deduced for the case of reflection and refraction near the critical angle. A very small change in the refractive index produces a very great change in the angle of deviation and in the amount of reflected light. A slight change in the angle of incidence may produce a very great change in the angle of deviation of the reflected or refracted ray.

In the first experiment a piece of Faraday glass was placed in a strong magnetic field, and one of the two interfering rays from a Jamin's interference refractor allowed to pass through it in the direction of the lines of force. When the ray was circularly polarised, a displacement of the bands was observed, the direction of which depended on whether the ray was right or left-handed circularly polarised. This displacement became less and less distinct as the ray was more and more elliptically polarised. Every ray is then broken up into its opposite circular components, and either the velocity of propagation, or the phase (period), or both, changes. The observed displacement was ·1355, while the value calculated from a double rotation of the plane of polarisation of 49° 20′ was ·137.

Several experiments for direct observation were made, which seemed to indicate no change in the velocity of propagation, but a change in the phase. In one of these experiments, a prism of glass was placed between the poles of a magnet, so that the rays were parallel to the lines of force and perpendicular to the first face of the prism, and were refracted out at the second face at a very large angle. Refraction then took place at a surface near the critical angle, and a slight change in the refractive index due to the induced magnetic stress would produce a very large deviation, in accordance with the equations found. The two halves of the narrow image were oppositely circularly polarised, so that each should have been displaced in the opposite direction. There should also have been a slight change in the intensity of the two halves. Nothing of the sort could be observed. Direct measurements of the rotation of the plane of polarisation, and comparison with a Fresnel's double quartz prism, showed that the effect was within the limits of observation if such a change in the refractive index had occurred.

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14. *Determination of the Heliographic Latitude and Longitude of Sun-spots. By* Professor A. W. THOMSON.

In the 'Observatory,' published monthly, we have for any day—The Position Angle of the Sun's Axis, and the Heliographic Latitude and Longitude of the Centre of Sun's Disc.

The method devised by me consists in throwing the image of the sun from an equatorial telescope on to a disc representing the sun, with lines of latitude and longitude drawn thereon, and reading off the latitude and longitude of any spot.

The latitude of the centre of sun's disc varies from 0° to about 7°; a cardboard

[1] Inaugural Dissertation, '*Ueber die magnetische Drehung der Polarisationsebene und einige besondere Fälle der Refraction.*' Berlin, Aug. 12, 1885.

disc for each whole degree is prepared, and is in fact an orthographic projection of a sphere turned through an angle equal to the latitude for which it is drawn.

The proper disc for the day of observation is taken and set to the angle corresponding to the position angle of sun's axis; the disc is held at that distance from the eyepiece of the telescope, which allows the image of the sun to exactly coincide with it. The latitude is then read off; and the longitude is found by taking the longitude of centre of disc given in the table, and subtracting or adding the difference as shown in the cardboard disc.

The paper of which the above is an abstract had appended to it a set of cardboard discs suitable for actual use, and tables required for the construction of these discs.

WEDNESDAY, SEPTEMBER 16.

The following Papers were read:—

1. *On the Nature of the Corona of the Sun.*[1] *By* William Huggins, *D.C.L., LL.D., F.R.S.*

Mr. De La Rue in his address before Section A in 1872, said truly:—'The great problem of the solar origin of that portion of the corona which extends more than a million of miles beyond the body of the sun, has been by the photographic observations of Col. Tennant and Lord Lindsay in 1871 finally set at rest, after having been the subject of a great amount of discussion for many years.' (Report Brit. Assoc. 1872, p. 6.)

Professor Hastings has recently revived the theory of Delisle that the corona is an optical appearance due to diffraction. He bases his view upon the behaviour of the bright line 1474, which he saw in his spectroscope change in length east and west of the sun, during the progress of the eclipse at Caroline Island in 1883. Captain Abney's discussion of the photographs taken by the English observers shows that there was considerable diffusion during the eclipse, and that therefore the observation of Professor Hastings may have been due to a scattering by our air of the light from the brighter part of the corona, and therefore may not indicate any change in the corona itself.[2] During the time that Professor Hastings observed the change in the length of the line 1474, photographs of the corona were taken by M. Janssen, and by Messrs. Lawrance and Woods. M. Janssen says: 'Les formes de la couronne ont été absolument fixes pendant toute la durée de la totalité.'[3] The photographs taken by Messrs. Lawrance and Woods (now in Captain Abney's hands for discussion) show that the corona suffered no such alterations in form as would be required by Professor Hastings' theory during the passage of the moon across the sun.

The evidence seems to be conclusive that the corona which comes into view at a total eclipse corresponds to an objective reality of some kind existing about the sun. It is difficult on any other hypothesis to explain satisfactorily:

1. The observed and photographed spectra which vary at different parts of the corona.
2. The visibility of the planets Venus and Mercury as dark bodies when near the sun.
3. The filamentous, and especially the peculiar curved structures seen in photographs of the corona.

[1] The chief points of this discussion of the nature of the corona were suggested in a Discourse on the Solar Corona given at the Royal Institution, February 22, 1885. A more full discussion of these points will be found in the Bakerian Lecture, 1885, in the *Proc. Roy. Soc.*, vol. xxxix. p. 108.

[2] *Report of Expedition to Caroline Island*, 1883, Washington, p. 105.

[3] *Annuaire pour l'an* 1884, p. 859.

4. The close agreement of photographs taken at different times during an eclipse, and especially between photographs taken during the same eclipse at places many hundreds of miles apart.

Considering the force of gravity on the sun, and the circumstance that comets have passed unscathed through the coronal regions, we cannot regard the corona as a true solar atmosphere, that is, as a continuous mass of gas held up by its own elasticity, which extends several hundred thousand miles above the photosphere.

Up to a certain point the spectroscope gives to us definite information as to the condition of the matter about the sun which forms the corona. We learn that there is incandescent solid or liquid matter, which also reflects to us light from the photosphere. The spectrum of bright lines, which is relatively fainter and varies greatly at different eclipses, tells us of glowing gaseous matter which accompanies the solid or liquid matter. As the solid or liquid matter can exist in the corona only in the form of discrete particles of extreme minuteness, *the corona must consist of a fog, in which the particles are incandescent*, and *in which the gaseous matter does not form a continuous atmosphere.*

It has been suggested that the matter of the corona is furnished by meteoroids, and by the lost matter of the tails of comets. Though some planetary meteoroids may be thrown into the sun, and there are meteoroids which doubtless fall directly into the sun from space, yet we can scarcely suppose so steady an inflow of meteoroids as would be needed to maintain the corona in the state of permanence in which we know it to exist. A similar difficulty presents itself more strongly on the view that the corona is fed by the débris of comets' tails.

It seems to me much more probable that the matter of the corona is supplied by the sun. This view is supported by the spectroscopic evidence, for the coronal gas is shown to consist of substances which exist also in the photosphere. The structure seen in the corona is much more in harmony with the view that the matter is going up from the sun, than that it is coming down upon the sun.

We have now to consider under what dynamical conditions matter coming from the sun can take on forms such as those we see in the corona, and can pass away to such enormous distances, in opposition to gravitation, which is so powerful at the sun.

There is another celestial phenomenon very unlike the corona at first sight which may furnish a clue to the true answer to this question. The head of a large comet presents us with luminous streamers, rifts, and curved rays, which are not very unlike, on a small scale, some of the appearances which are always present in the corona. We do not know for certain the conditions under which these cometary phenomena take place, but the only theory upon which they can be satisfactorily explained, and which now seems to be on the way to become generally accepted, attributes them to electrical disturbances, and especially to a repulsive force acting from the sun, probably electrical, which varies as the surface, and not like gravity, as the mass. A force of this nature in the case of highly attenuated matter can easily master the force of gravity, and as we see in the tails of comets, blow away this thin kind of matter to enormous distances in the very teeth of gravity.[1]

If such a force of repulsion, acting from the sun, is experienced in comets, it must also be present near the sun, and may well be expected to show its power over the matter ejected from the sun. Such a force would be present if we suppose the sun's surface to possess permanently an electric potential of the same name. The sun may acquire such a potential from processes always going on, or if once charged, would doubtless remain so, and on this supposition it is not necessary to assume local electrical disturbances. But electrical disturbances must be present on the sun on a very grand scale in connection with the ceaseless and fearful activity of the photosphere. Through these disturbances the ejected matter might come

[1] *Proc. Roy. Inst.*, vol. x. p. 9. Also papers by Bredichin in the *Annales de l'Observatoire de Moscou*, and *Astr. Nachr.*, No. 2411. Also Stokes, *On Light as a Means of Investigation*, p. 70 *et seq*. See also papers by Professor Young in the *Amer. Jour. Science*; and by Mr. Proctor in *The Sun*, 3rd ed., pp. 326–427.

to have a higher potential than it possessed as forming part of the sun, and in this way too might come about some of the varying conditions upon which the observed changes in the corona may depend.

The photosphere is the seat of ceaseless convulsions and outbursts of fiery matter. Storms of heated gas and incandescent hail rush upwards, or in cyclones, as many miles in a second as our hurricanes move in an hour. Is it then going beyond what might well be to suppose that some portions of the photospheric matter, having an electric potential of the same name as that of the solar surface, and ejected, as is often the case, with velocities not far removed from that which would be necessary to set them free from the sun's attraction, should come under the action of an electric repulsion, and so be carried upwards from the sun?

If we accept this view of things, many of the coronal phenomena can be satisfactorily explained.

1. The very long coronal rays, which rest upon sufficient testimony, no longer appear improbable.

2. The peculiar curved rays within the corona may well arise from the smaller rotational velocity of the photospheric matter, which would make it lag behind as it rose from the sun, and from probably varying directions of the force of eruption combined with the repulsive force acting radially.

3. We should expect to find the largest coronal extensions over the spot-latitudes where solar activity appears to be greatest.

4. We have an explanation of the rapidly increasing tenuity of the coronal matter from the sun, as the repulsion existing between the similarly electrified particles would cause them to separate from each other.

5. The gas carried up with the solid or liquid particles would constantly vary in amount, and also in the height to which it was carried as a gas. This state of things is in accordance with the great differences observed in the spectra of different parts of the corona, and in the spectra of the same parts at different times.

6. If the corona consists of electrified particles, it may well be that the planets. especially Venus and Mercury, may have an influence in determining the mode of outflow of this electrified matter in the directions in which they happen to be. M. Trouvelot, in his report of the eclipse of 1878,[1] pointed out that the two great coronal extensions which were remarkable at that eclipse were directed respectively to the planets Mercury and Venus. General Tennant informs me that some recent calculations show that at the eclipse of 1871 the positions of Mercury and of Venus coincided with the two positions of greatest coronal extension. He considers further that at the eclipse of 1882 the combined effect of these planets is distinctly shown 'in the protruding angle at the upper left side of the engraved corona in the "Phil. Trans." 1882.'

7. It seems obvious, that, if the corona is due to a supply of matter and to forces coming from the sun, the coronal structure and the degree of extension which are produced by them at any part of the sun, would continue to be produced by these agencies at that part of the sun; and in that sense the corona would rotate. In the case of the more distant and diffused parts the rotation could scarcely be of one and the same material object, any more than in the sweep of a comet's tail at perihelion. The action of any external force, as that of a planet, would continue to be in the direction of this object, and independent of the solar rotation.

8. Eye-observations, and photographs taken with different exposures appear to show that the corona has not an outer boundary, but that it is lost in increasing faintness and diffusion. Many of the coronal particles under the influence of the electric repulsion would leave the sun, and at the same time separate more widely from each other, becoming too diffused to be longer visible.

9. This ceaseless outflow of extremely minute particles from the sun, very widely separated from each other, may possibly throw some light on another phenomenon which has not yet been satisfactorily accounted for, namely, the zodiacal light.

10. The view of the sun as an electrically charged body may throw some light

[1] *Report of Total Eclipse*, 1878; Washington, p. 93.

on the mode in which the sun acts upon our magnets. The sun being a permanently charged conductor separated from the earth also a conductor, by an insulating vacuum, would affect the distribution of the earth's electricity by its power of statical induction. As the earth rotates, currents would be set up about it to effect the redistribution of electricity required to satisfy the inducing influence of the sun. May we not find in these earth currents an explanation of some of the phenomena of the earth's magnetism? However this may be, the changes in the sun's statical induction which follow from the shooting forth of the electrified matter of the corona may well so affect the earth's currents as to bring about the disturbances observed in the needle in connection with solar phenomena.

11. If further evidence should be forthcoming in support of the observation of M. Trouvelot in 1878, and of the results of General Tennant's calculations as to influence of Mercury and Venus on the corona, there would be some probability that Venus and Mercury were permanently charged with electricity of the other name to that of the sun. If this should be found to hold good of the other planets, we should have the planets charged with one kind of electricity, and the sun charged with the opposite electricity. As we have reason to believe that the sun and planets formed originally one cosmical mass, the question may be suggested whether these charges of electricity of opposite names can have been brought about in connection with the separation of the planetary bodies.[1]

2. *On the Spectrum of the Stella Nova visible on the Great Nebula in Andromeda.* By William Huggins, *D.C.L., LL.D., F.R.S.*

This star has appeared very near the position of greatest condensation in the great nebula in Andromeda. On the evening of September 3 it presented the appearance of an orange-coloured star of from the seventh to the eighth magnitude. When viewed in a spectroscope of small dispersive power, a continuous spectrum was seen which could be traced from about C in the red to a little beyond F. There appeared great brightness from about D to about *b*, which suggested strongly the presence of bright lines in that part of the spectrum. When a more powerful spectroscope was employed, the suspicion of some bright lines in this region was strengthened, but this point could not be certainly determined.

On September 9 the star was again observed. The colour of the star appeared less strongly orange. In the small spectroscope the great brightness about D was not so marked, but the suspicion of bright lines in the region from D to *b* was confirmed; and the appearance of the spectrum in the large spectroscope left little doubt on my mind as to the existence of from three to five bright lines in this part of the spectrum.

3. *On the Bright Star in the Great Nebula in Andromeda.* By Ralph Copeland, *Ph.D.*

The author very shortly reviewed the history of the great nebula from the time of Al Sûfi, towards the close of the tenth century, to the present moment, the object being to show that there is no evidence of any actual change in the nebula itself. Passing to the recent sudden display, the author quoted various observations, beginning with Mr. Tarrant's on July 2, and ending with that of the Rev. S. H. Saxby on August 9, showing that on the whole there were some premonitory symptoms of an outbreak in or near the nucleus of the nebula. The first positive evidence of the presence of an actual star is given by Mr. J. W. Ward, who saw a star-like nucleus of about the ninth magnitude at Belfast at 11 P.M.

[1] Since this paper was read my attention has been called to the following papers by Professor Osborne Reynolds: 'On the Tails of Comets, the Solar Corona, and the Aurora, considered as Electric Phenomena,' Mem. *L. and P. Soc.*, Manchester, 3rd series, vol. v. p. 44; 'On Cometary Phenomena,' *ibid.* p. 192; 'On an Electrical Corona resembling the Solar Corona,' *ibid.* p. 202; On the Electrodynamic Effect which the Induction of Static Electricity causes in a Moving Body. This Induction on the part of the Sun, a probable cause of Terrestrial Magnetism, *ibid.* p. 209.

on August 19. Unfortunately, bad weather prevented a confirmation, and consequent announcement of this most important observation. The first published observation of the appearance of a bright star in the nebula is that of Dr. Hartwig, at Dorpat, on August 31. Estimates of the brightness were found by the writer to depend largely upon whether the effect of the nebulosity was eliminated or not. Estimates with low powers included some of the nebulosity, and made the star appear too bright. The spectrum was observed on various nights, beginning with September 1. The spectrum is almost absolutely continuous from end to end, and only on the closest scrutiny can the faintest irregularities be even suspected. The spectrum extended from W.L. 600^{mmm} to 456^{mmm}, with a maximum about 544^{mmm}. A point less obscure than the rest gave W.L. 482 (not far from F.) On September 3 Lord Crawford, in company with the author, detected a nebulous nucleus $17''\cdot0$ from the bright star. By micrometrical comparison with a neighbouring star, of which Lord Rosse gave the relative position in 1851, the author found that this nebulous nucleus now visible is really that of the Great Nebula. He then quoted from the 'Astronomical Register' of November 1882, as follows: 'A small star *s.p.* the nucleus of the great nebula in Andromeda (M. 31) has been suspected of variation by the Rev. T. W. Webb. He found the star readily visible on several occasions with a $9\frac{1}{3}$ inch "With" speculum, while at other times he found it very faint with the same instrument.' At present there is no star visible, except Dr. Hartwig's, at all corresponding to the one seen by Mr. Webb.[1] It seemed, therefore, to the author 'not unlikely that the true state of affairs is expressed by Lord Rosse in a letter dated the 9th inst., viz., "*It would appear to be the abnormal blazing out of a quick, faint, variable star, rather than the appearance of a new star which has never been seen before.*"' The spectroscopic observations are in accord with this opinion, for the spectrum is not unlike that of a variable star, while it presents no resemblance to that of a genuine blazing star like those of 1866 and 1876.

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4. *On Solar Spectroscopy in the Infra Red.* *By* Dr. Daniel Draper.

In the year 1877 Professor Piazzi Smyth, who had just re-observed in Lisbon Brewster's three celebrated lines in the ultra red of the solar spectrum, X, Y, and Z, was in correspondence with the late Dr. Henry Draper about them, as being the furthest lines visible to the human eye in that direction, and was informed by him that his father, Dr. J. W. Draper, claimed these lines, as being the lines he had photographed so long before as in 1842, and called α, β, and γ.

Therefore it became Professor Piazzi Smyth's rather painful duty to point out that that was a mistake; for the lines α, β, and γ in Dr. Draper's photograph were far beyond the possible spectrum places of Brewster's X, Y, and Z.

But when, in a few years more, Captain Abney by improved photography, and then Professor Langley with his admirable bolometer, brought into view whole regions of lines beyond and outside Brewster's furthest X, Professor Piazzi Smyth suggested to Dr. Daniel Draper (Dr. Henry Draper having died in the interval), that the time had arrived for comparing his father's primitive photograph of 1842 with the recent discoveries, and ascertaining whether his lines α, β, and γ corresponded in any way therewith.

The answer that Dr. Daniel Draper gives, is to the effect that they do correspond, and in so remarkable a manner as to add great value to photographic testimony on a Daguerreotype plate.

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5. *The Errors of Sextants as indicated by the Records of the Verification Department of the Kew Observatory, Richmond, Surrey.* *By* G. M. Whipple, *B.Sc., F.R.A.S.*

The author gave the history of the verification of sextants at the Observatory from its establishment in 1862, describing the apparatus employed devised by Mr.

[1] Unless indeed Lord Rosse's star is identical with Mr. Webb's, as was suggested by Mr. G. J. Stoney. *Note added* Nov. 6, 1885.

F. Galton, Mr. T. Cooke, and himself. Stating that the verification of the instruments comprises four stages; viz. Examination of (1) telescopes, (2) mirrors, (3) dark shades, and (4) errors of eccentricity and graduation of the arc, he detailed the various operations conducted in each stage, and finally classified the frequency of the various defects as determined from upwards of 169 instruments verified at the Observatory during the past year:—13 per cent. were defective in stage 2, 5 per cent. in stage 3, and 10 per cent. in stage 4. An analysis of all the instruments under test (4) showed that 20 per cent. had errors amounting to 30″, 30 per cent. amounting to 60″, 25 per cent. amounting to 120″, and 7 per cent. amounting to 180″; whilst only 2 per cent. fell below 20″, and were practically perfect in their gradation.

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6. *On the Behaviour of First-class Watches whilst undergoing tests in the Rating Department of the Kew Observatory, Richmond, Surrey. By* G. M. WHIPPLE, *B.Sc., F.R.A.S.*

The watch-rating department of the Kew Observatory, Richmond, Surrey, has been established in order to provide makers and the public with certificates of the accuracy of the performance of good watches. The conditions of the trials adopted for three classes, A, B, C, for watches of different qualities, which are detailed below, are similar to those in use at the Geneva and Yale Observatories.

The following table will indicate the nature of the trials to which the certificates refer, the variation of rate being determined daily:—

Position of Watch during test	For Certificate of Class		
	A	B	C
Vertical, with pendant up	10 days	14 days	8 days
„ „ „ right	5 „	—	—
„ „ „ left	5 „	—	—
Horizontal, with dial up	5 „	14 days	8 days
„ „ „ down	5 „	—	—
„ at temp. 85° F.	5 „	1 day	—
„ „ 35° F.	5 „	1 „	—
Not rated (intermediate days) . .	5 „	1 „	—
Total duration of test	45 days	31 days	16 days

The results derived from of recent trials of 134 watches were given in a tabulated form, and were contrasted with similar numbers derived from foreign trials.

The number of failures to obtain certificates were—

14 per cent. for variation of rate
8 „ „ „ due to position
0·5 „ „ imperfect temperature compensation
3 „ „ other causes.

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7. *On a recent Improvement in the Construction of Instruments graduated upon Glass. By* G. M. WHIPPLE, *B.Sc., F.R.A.S.*

The very clever invention of Messrs. Negretti & Zambra some years ago of running a slip of white enamel in the glass at the back of the bore of the tube of a thermometer has been most highly valued by scientists. I now submit to the notice of members of the Association a number of thermometers, eudiometers, graduated measures, &c., in which a valuable extension of the use of enamel has been carried out by Mr. Jas. J. Hicks, of 8 Hatton Garden, London.

In the case of thermometers the enamel is caused almost to surround the stem, leaving but an aperture through which to view the mercurial column. This enables the graduation to be made and the figures to be etched immediately in front of the enamel, and consequently gives them a clearness and distinctness as far superior to the ordinary tube as that is to the old-fashioned instrument with clear glass stem.

The application of the enamel to the construction of the variety of fluid measuring glasses now in use is quite new, I believe, and will be of great service in laboratories and all places where such articles are in use. In this case the enamel is not caused to almost surround the measure, but alternate segments of the sides of the glass are clear and opaque, so that a view of the fluid being measured is obtained through the spaces, and the graduations stand out distinctly on the white surfaces. Specimens of the different instruments were laid on the table.

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8. *On Methods of preventing Change of Zero of Thermometers by Age. By* G. M. Whipple, *B.Sc., F.R.A.S.*

The author, having referred to methods which have been adopted at various times to rectify the rising of the zeros of mercurial thermometers by age, exhibited to the meeting certain instruments which had been annealed in accordance with a practice in use for many years in the construction of standard thermometers at the Kew Observatory. These have been made by Mr. Hicks, of Hatton Garden, who has erected special apparatus for the purpose, and apparently show that the desired result has been attained.

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9. *On a new and simple form of Calorimeter. By* Professor W. F. Barrett.

With this instrument no corrections for the heat capacity of the vessel used or of the thermometer are necessary, and only a small correction for the loss by cooling. The bulb of the thermometer forms the cup that holds the liquid, and the stem the beam of the balance that enables its weight to be found. The temperature, T, of the warm liquid is given by the thermometer that plugs the burette as the liquid flows into the empty cup, the temperature of which is raised from t to θ. If C be the constant of the instrument and W the weight of water used, the heat lost is equal to the heat gained by the instrument, or $W(T-\theta) = C(\theta - t)$, whence

$$C = W\frac{T-\theta}{\theta - t}.$$

Hence a liquid of sp. heat S and weight W, having an initial temperature T, and which raises the temperature of the calorimeter from t' to θ' is found as follows:

$$S = \frac{C(\theta' - t')}{W_1(T_1 - \theta')}.$$

The constant C for each instrument is determined once for all and the operation then becomes a very simple and speedy one. A polished metal cap fits over the cup to prevent evaporation. The instrument is the joint invention of the author and of Mr. J. McCowan, Demonstrator of Physics in the Royal College of Science.

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10. *On a modification of the Daniell Battery, using Iron as Electropositive Element. By* J. J. Coleman.

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11. *On a new form of Galvanometer.* *By* Professor JAMES BLYTH, *M.A.*, *F.R.S.E.*

The author described a method of measuring electric currents by means of an instrument whose scale is graduated to equal divisions, and whose deflections are, from the intrinsic nature of the instrument, proportional to the current strength through all ranges.

In principle the instrument depends upon the mechanical action exerted by a magnetic field upon a movable conductor carrying a current. In construction it is essentially similar to the well-known apparatus, due to Faraday, for showing the continuous rotation across the lines of magnetic force of a horizontal radial conductor carrying a current and having slipping contacts at its centre and circumference. The construction will be understood from the following description.

Two bundles of permanently magnetised steel wires are made up in the form of cylinders having narrow axial holes. These are fixed with their axes in the same vertical line, separated by a narrow gap, and so that the north poles of the one set of magnets face the south poles of the other. In this gap the magnetic field is sensibly uniform and the lines of force vertical. Inserted in the gap is a thin circular disc of wood or vulcanite, having a central mercury cup and a concentric circular mercury trough at a short distance from it. A stout brass rod is provided, having a short thick copper wire rigidly attached at right angles to its lower end. Its upper end passes freely through the axial hole in the upper magnet, and is rigidly attached to the lower end of a long fine torsion wire of steel or silver, whose upper end is fixed to a suitable support. The lower end of the brass rod dips into the central mercury cup, and the outer end of the copper wire (bent down a little at right angles) dips into the concentric canal of mercury. Stout copper wires are led from the central cup and canal to binding-screws suitably placed so as to form the terminals of the instrument. The upper end of the brass rod, which projects a little above the upper magnet, carries a long pointer, which moves over a horizontal circular disc, graduated either to degrees or to show amperes directly. This disc is fixed with the torsion wire passing freely through its centre. The whole is so enclosed as to be free from air current.

The action of the instrument will be easily understood. Suppose a current sent through it. As is well known, the electromagnetic force acting on the radial current will tend to make it rotate in a horizontal plane with a uniform force. This rotation will go on till a certain angle is reached, when the moment due to the electromagnetic force is balanced by the moment due to the torsion of the wire.

Let

i = the current strength,
a = the length of the radial wire,
N = the magnetic induction,
A = the torsion constant,
θ = the angle of equilibrium,

we have

$$\tfrac{1}{2}ia^2N = A\theta\,; \quad \text{or} \quad i = \frac{2A}{a^2N}\theta,$$

showing that the current strength is proportional to the angle of deflection.

The instrument admits of several modifications. Two have been constructed in addition to that above described. In the one the permanent magnets are replaced by similarly placed electromagnetic coils, through which the current to be measured passes. In this case the square of the current strength is proportional to the angle of deflection. In the other the fixed magnets are dispensed with, and, instead, a cylindrical bundle of magnets is fixed coaxially to the brass rod, but insulated from it, so that it rotates along with the rod and radial wire. In this case the radial wire projects from the middle of the length of the magnet bundle, while the lower end of the brass rod is prolonged so as to dip into a mercury cup at a considerable distance below the lower end of the bundle. Owing to the influence of the exterior part of the circuit leading from the mercury canal to

the cup, the equation for this case is a little more complicated. With proper arrangements, however, the deflection can be shown to be proportional to the current strength.

In the instruments constructed for practical use the mercury cup and canal are so made, on the unspillable ink-bottle principle, as to preserve the mercury in case of being knocked over or even inverted.

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12. *On the Physical Conditions of Water in Estuaries.*[1] *By* HUGH ROBERT MILL, *B.Sc., F.R.S.E., F.C.S.*

Observations have been made on the estuaries of several of the most important Scottish rivers, of the temperature and density of the water at various positions.

The temperature was observed by means of Negretti & Zambra's Standard Deep-Sea Thermometer, in a special frame devised in order to permit of the instrument being worked in shallow water and in places where the current is rapid. A modification of the slip water-bottle for the same conditions was made and found to work admirably.

Estuaries were found to be capable of division into three classes:—

1. Those in which all the salt water is withdrawn from the estuary by the ebb-tide, *e.g.*, the Spey. Here the river water freshens the surface of the surrounding sea, but affects the deep water very slightly.

2. Those in which the salt water is partially withdrawn, *e.g.*, the Tay. Here the river is brackish at low tide and the surface water of the surrounding sea is slightly freshened.

3. Those in which salt water always remains, *e.g.*, the Forth. Here at the river end the density of the water varies with the tide, but is always low; it rises rapidly in the first twelve miles and thereafter, proceeding seaward, it rises very gradually. The density of surface and bottom water approaches coincidence as the sea is neared, and the merging of the estuary into the sea is marked by a very slight decrease of density throughout the entire depth. There is no seasonal variation of density, but during a flood the freshening is perceptible all along the line in decreasing amount.

Temperature has a continually diminishing annual range as the sea is approached. In summer it falls, and in winter it rises, at first rapidly and then gradually from river to sea. The mean annual temperature at each point is the same (47·5). Bottom water is colder in summer and slightly warmer in winter than that at the surface.

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13. *Further Experiments in Photo-Electricity.* *By* Professor MINCHIN.

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14. *On the Formation of a Pure Spectrum by Newton.* *By* G. GRIFFITH, *M.A.*

In English text-books it is generally stated that Wollaston was the first to observe a pure spectrum, and that Newton did not know how to form one.

The author referred to several statements of this character (Professor W. Allen Miller, 'Chemical Physics,' 3rd edition, p. 161; Professor Roscoe, 'Spectrum Analysis,' 1869, p. 22; see also Parkinson's 'Optics,' 1859, pp. 143–45.)

These accounts are probably to be traced to a passage in Sir David Brewster's 'Life of Newton' (vol. i. p. 117 of the large edition, or p. 58 of the new and revised edition, 1875). 'Had Newton received upon his prism a beam of light transmitted through a very narrow aperture, he would have anticipated Wollaston and Fraunhofer in their fine discovery of the lines in the prismatic spectrum.' In a previous passage Brewster has described how Newton first formed a spectrum by using light which had passed through a round hole in a shutter.

[1] Published *in extenso* in the *Scottish Geographical Magazine*, Vol. II. pt. i.

Although Newton admitted light into his darkened room in this way for certain experiments, yet he was perfectly aware that the coloured image which is formed when such a beam is passed through a prism consists of innumerable coloured circles ('Opticks,' Prop. iv., Prob. 1, I), which overlap, and that the mixture of the heterogeneous rays can be diminished by making the circles of smaller diameter. The first method which he proposed for doing this was to have the hole at a great distance from the prism, so that rays coming from the centre only of the sun would be used.

Then follows this passage: 'But that those circles may answer more distinctly to that hole, a lens is to be placed by the prism to cast the image of that hole upon the paper. If this be done it will not be necessary to place that hole very far off; no, not beyond the window.'

He then describes fully how this is to be carried out practically.

This passage is followed by another, which, strange to say, has escaped the notice of Brewster and many others, 'Opticks,' p. 59, 2nd ed. 'Yet instead of the circular hole (F), 'tis better to substitute an oblong hole shaped like a long parallelogram, with its length parallel to the prism (A, B, C). For if this hole be an inch or two long, but a tenth or twentieth part of an inch broad, or narrower, the light of the image "*i.e.* the spectrum" (*pt*) will be as simple as before or simpler, and the image will become much broader and, therefore, more fit to have experiments tried in its light than before.'

He also says that a triangular aperture may be used, the base of the triangle being about the tenth of an inch, its height an inch or more. In the spectrum formed by light passing through such an aperture, he says that the bases of the triangular images overlap a little, but their vertices do not.

In all these experiments the prisms were placed at the angle of minimum deviation. The lens was generally placed at a distance from the aperture equal to double its focal length, and the screen at the same distance from the lens. The prisms are carefully described; one is stated to have 'had some veins running along within the glass from one end to the other, which scattered some of the sun's light irregularly.' Others are described as being 'free from veins.' He also used prisms filled with rain-water. In one of his letters to Oldenburg, Horsley's 'Newton,' vol. iv. p. 343, he refers to a crystal prism. This must have been rock crystal.

Very ordinary prisms will show the Fraunhofer lines. Prof. Rood using the prisms of an ordinary candelabrum found no prism among twelve which did not show several lines. It seems now impossible to account with certainty for their not being seen by Newton; it certainly was not for the reason given by Brewster. Nor probably was it due to the inferior quality of the glass or workmanship of the prisms. Newton used an assistant for observing the spectra in certain experiments. 'Opticks,' p. 110 (2nd ed.) 'An assistant, whose eyes for distinguishing colours were more critical than mine, did by right lines,' . . . 'drawn across the spectrum, note the confines of the colours.' It is possible that this assistant may have seen the lines, but Newton's attention was not called to them, and their existence was not recorded by him.

For full details of many of Newton's experiments it is necessary to refer to the 'Lectiones Opticæ,' which were not published until after Newton's death. They were delivered in the years 1669–71, at Cambridge, where the original manuscript was deposited.

In one of the early lectures he describes his observation of the spectrum of the planet Venus. 'The object glass of a seven-foot telescope, its aperture being two inches and more broad, to transmit a sufficient quantity of rays,' received the light of the planet, and formed upon a paper at the distance of seven feet an image 'like a lucid point.' A prism being then interposed, the spectrum formed is described as 'a very fine line, though not very bright, however very easily to be discerned.' He then remarks: 'And I believe the same thing might be observed of stars of the first magnitude, as of Sirius, especially if a lens be used four or six inches broad, that it may transmit many rays.' In a subsequent page it is stated that this experiment had been successfully tried.

This interesting observation is given, in terms which are substantially the same, in a letter addressed to Oldenburg, and dated Cambridge, April 1672 (Horsley's 'Newton,' iv. p. 311). In the letter the spectrum of Venus is described as a 'long splendid line.'

In conclusion, the author referred to the brief but correct account of Newton's experiments described in the early part of the paper, by Lloyd in his 'Undulatory Theory,' and in Verdet's Works, iii. p. 253.

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15. *On the Use of Bisulphide of Carbon Prisms for cases of Extreme Spectroscopic Dispersion, by* Professor C. PIAZZI SMYTH; *and their Results in Gaseous Spectra, commented on by* Professor ALEXANDER S. HERSCHEL, *M.A., F.R.S.*

The serious loss of light which occurs by absorption in long trains of dense glass prisms was attempted to be diminished by the first author using, in place of the usual flint-glass prism between two correcting crown-glass ones, a bisulphide of carbon prism with a refracting angle of 104°. A train of such compound fluid prisms of 2·1 inches optic apertures, together with two simple flint-glass prisms, each of 64° refracting angle, dispersed the spectrum between A and H over an angle of about 60°. The spectrum so formed was examined with an inspecting telescope of 2·25 inches aperture, 32 inches focal length, and of magnifying power 36. About one-seventh of the whole length of the spectrum could be commanded at one time by the range of the micrometer-screw which moved the inspecting telescope in angle, without resetting the prism train to minimum deviation for the next adjoining portion of the spectrum.

After overcoming the tendency of the interior glass faces to contract a film from the cement used in the prisms, by repeated washings, the well-known difficulties of inequality of temperature in the fluid prisms, disturbing their homogeneity and altering the total dispersion of the train, had then to be contended with, and were obviated sufficiently for relative measurements by the use of non-conducting coverings of the prisms, and by guarding carefully in each set of observations against accidental changes of temperature in the room.

With the spectroscope so arranged the first electric spectrum of a vacuum tube examined, was that of oxygen gas. The four distinct lines of the so-called compound spectrum of the gas were identified, and three of them proved on examination with the instrument's high dispersive power to be really compound, each of the three being resolved into a delicate line-triplet. Three similar line-triplets in regular configuration with these in neighbouring parts of the spectrum were also found, while a strong oxygen line, in addition to other single lines of the spectrum, was detected in the ultra-red at a distance from the ordinary field of chromatic light in that direction greater than that of any elementary gas-spectrum line yet ocularly measured.

Of the numerous array of lines produced in hydrogen-tubes which have been ascribed to hydrogen, 1,616 lines were well seen and measured, most of them extremely sharp and beautifully precise lines. Of these 1,442 are in the space where 448 such lines are recorded in the hydrogen line catalogue of this gas's compound spectrum in the Report and tables of the wave-lengths of the elements, presented last year by the Spectroscopic Committee of the British Association,[1] 20 are beyond the violet, and 154 are beyond the red limit of the range of the same catalogue in that Report.

As another example of the great resolving and defining powers of the bisulphide of carbon prism spectroscope, it may be noted that in a single fluting of the compound spectrum of nitrogen near the solar line D, in which twenty linelets and haze-bands are figured in the extensive map of that spectrum recently communicated to the Imperial Academy of Sciences of St. Petersburg by Dr. Hasselberg, 161 sharp lines were seen and mapped with the train of fluid prisms, while only three wave-lengths of the leading edges in the same fluting are noted

[1] *British Association Reports*, 1884, p. 390.

in the table of the compound spectrum of nitrogen of the Report already quoted. Again, in place of the 115 wave-lengths of haze-band edges, noted as forming the whole fluted or compound spectrum of nitrogen in that Report, scarcely less than 7,000 lines of the same spectrum have been so clearly seen and distinguished in it with the bisulphide of carbon spectroscope, as to be all mapped and delineated on the lithographic plates of the results obtained with this spectroscope, which will be published in the next, now nearly completed, volume of the Transactions of the Royal Society of Edinburgh.

The measurements of this gas-spectrum's exceedingly full crowd of lines were rendered possible in great measure by end-on vision-tubes of nitrogen of very superior purity and brightness, produced for the author by Mr. C. Casella, the electric excitation of the tubes being also brought under exceptionally regular control by a new battery and five-inch spark induction-coil specially supplied to him for this purpose by Mr. Alfred Apps, of London.

A fourth example of the spectroscope's great optical efficiency was its complete disentanglement of the remarkable web of fine lines forming the green band of the electric spectrum of carbonic oxide. When seen through a spectroscope of this power a curious crossing presents itself near the band's brighter edge, arising from the concurrence there, apparently, of two really distinct but not easily separable series of very similarly arranged linelets, of which the band's line-cluster must at least consist. In Professors Angström and Thalén's drawing of it ($1\frac{1}{4}$ inch long) in their 'micrometric measurements,'[1] the details delineated only amount to fourteen separately represented light maxima of the gradually decreasing band. But with the expansion of this length which the micrometer-screw's automatic tracing point of the bisulphide of carbon prism spectroscope effected on its paper page, from $1\frac{1}{4}$ inch to 26 inches (corresponding in its scale to nearly 4 inches for the interval between the two sodium D lines, and to about 220 feet in length for the whole visible extent of the spectrum from A to H), no haziness of light was any longer to be seen, but instead of it a series of 43 sharp linelets in this space were plotted accurately in their true relative positions by the recording pointer on the paper.

Even with this automatic means of registration, however, the task of projecting the prodigious multitude of sharp lines observed in the several different gases submitted to examination, demanded the writer's available diligence towards this end too constantly to allow him to give special attention to any harmonic or other numerical relations which may exist among the abundant data thus collected, although researches of this kind hereafter are not proposed to be omitted. A notable example of the probable prevalence of such relations, and a striking corroboration of the clear vision and accuracy reached in the projections, presented itself, however, in the mapped places just now described of the 43 carbonic oxide green-band linelets. A map of this band's evidently complete resolution into all its component linelets was sent for inspection to Professor Herschel, and it immediately suggested to him a simple law of progression which embraces all the lines mapped upon the sheet (of which a figure accompanied this paper) of this band's visible components; if, at least, duplicity of more than half the lines of one of its ranks be disregarded, which is so extremely close that it scarcely yet furnishes any material occasion for the paired lines' separate descriptions. The exactness of the surmised progression's agreement with the record is all the more noteworthy when it is stated that the latter includes measurements of intervals between some of its lines not exceeding the 50th part of the micrometer interval between the two sodium lines, and that within about that diminutive quantity also it everywhere agrees with the presumed line-places of the theoretical progression, whose range yet extends to many intervals between the sodium-lines along the linelet ranks.

The rank of split-lines of the green carbonic oxide band has successive intervals beginning from its first line which forms the leading (or least refrangible) edge of the green band, represented by the natural numbers, 1, 2, 3, 4, &c., with a space between the first two lines, or an arithmetical difference between the intervals of the succeeding lines, of about two British, or three-quarters of a metrical wave-

[1] *Transactions of the Royal Society of Upsala*, 1875.

number unit. Its procession remains in sensibly exact agreement with this rule to the seventeenth and eighteenth lines, still visible, and measured in the map. But it grows quickly fainter from the sixth line onwards, and presents signs of division and duplicity in its lines from about the ninth line onwards.

The other rank of lines (which completes the whole group) is identical in its intervals with the first, but its lines are not double, and, fading more slowly in brightness than those of the other rank, they form in the open part of the band its strongest array or main-line troop. Almost exact coincidence occurs of its tenth line with the eleventh line of the other rank, and the line intervals being there pretty wide, an appearance of crossing of the two series and of condensed brightness in the nearly doubled line forms the easily recognised and marked feature of the band already mentioned, not very far from its bright edge. Nearer to the edge than this the lines of the two ranks, nearly equal to each other in brightness, are unaccordant and intermixed in place with little apparent signs of orderly relation. But another crossing-point yet happens here (an arithmetical consequence of the former one), where the two ranks have a spectral line in common with each other. This is the leading line of the second or single-line rank, which coincides and is, as far as the observations can determine, identical with the fifth line of the projecting band-edge or split-line rank.

The new common line of the two progressions is not brighter by superposition than adjoining lines, preceding and following it, of the two ranks in which it falls; but the second rank of lines takes its origin in the fifth line from the band-edge or front line (inclusive) of the other rank, and being thus four intervals or ten unit-spaces $(1+2+3+4)$ distant from that edge, all its lines fall thus far in advance of those corresponding to them in the other leading or projecting file. It thus happens that its tenth line, instead of coinciding with the other file's tenth line, is advanced ten unit spaces of the progression from it, and falls into agreement, therefore, with the eleventh line of that rank, which is also ten unit spaces distant from the last preceding or tenth line of its serial progression, as the two lines are found to do quite accurately at the crossing-place of the band. For in the faithfully depicted map, the single or main line at this point exactly hides or takes the place of one of the two half-lines, which together should form a close pair of the split-line spectrum at that place. Both the great accuracy of the observations and the perfect correctness of the presumed law of line-interval succession seem to be alike proved, and established satisfactorily by this unintentional and yet most remarkably exact agreement.

The two partial linelet spectra of this band, as far as they were measured, agree with each other when superposed rather more perfectly than with the theoretical progressive points computed for them on the micrometric scale of the map; but this is to be expected, as the scale of prismatic dispersion, or of micrometric parts, is not identical with that of wave-numbers, in relation to which alone the rule of succession of the lines in intervals forming an arithmetical progression is in all probability exactly true. But the real identity of the formula, whatever it may be, for the two partial spectra is shown quite free from any such deceptions by confronting a copy of the lines of one with the lines of the other spectrum on the map, and observing the almost perfect superpositions which this yields, in each and every line. It seems allowable to speculate whether the occasional choice of valency which chemists find it necessary to ascribe to carbon, between bivalency and tetravalency in its varying power of forming saturated compounds, may not be connected with this twofold repetition, which here certainly exists, of one and the same rank of spectral lines in a single spectral band, thus shown by one of that element's abnormally saturated compounds under very vigorously electrified conditions.

Section B.—CHEMICAL SCIENCE.

President of the Section—Professor H. E. Armstrong, Ph.D., F.R.S., Sec.C.S.

THURSDAY, SEPTEMBER 10.

The President delivered the following Address:—

In the Chemical Section of the British Association for the Advancement of Science the advancement of chemistry throughout the British Empire must be a subject of commanding interest. Signs of such advancement are not wanting:—the rapid establishment of science colleges in one after another of our large towns; the establishment of the Society of Chemical Industry, which now, only in the fifth year of its existence, numbers over 2,000 members; the granting of a Royal charter to the Institute of Chemistry; the changes introduced at the London University in the regulations for the D.Sc. degree; the report of the Royal Commission on Technical Education, in which the value to chemical manufacturers of advanced chemical knowledge is so fully recognised; the important conference on education held at the Health Exhibition last year; the recent agitation to found a teaching university in London with adequate provision for research—surely all these are signs that the value of higher education must and will, ere long, be generally recognised.

The neglect of chemical research in our British schools has often been forcibly commented upon—of late, especially, by an eminent past-President of this Section, Dr. Perkin, whose opinion is of peculiar value, as he is not only world-renowned as a chemist, but also as a manufacturer: indeed, as the founder of two distinct important chemical industries. There can be no doubt of the fact and of the dire consequences to our country of such neglect: how is it, then, that such pronounced complaints have been so coldly received; that hitherto they have produced comparatively so little effect; and that such slight encouragement is being given to those who, notwithstanding the many difficulties in their way, have steadfastly devoted themselves to research work? I question whether the value of such work has yet been brought home to teachers generally, let alone the public: the '*cui bono?*' cry is almost invariably met by pointing to some discovery of great pecuniary value as the outcome of research. This argument educationalists very properly refuse to recognise. Too little has been said as to the cause of the neglect so bitterly and properly complained of. Hence it is that I propose again to take up what many may regard as a somewhat threadbare theme.

Everyone will agree with Professor Sir Henry Roscoe, who in his address last year to this Section said 'that those who are to become either scientific or industrial chemists should receive as sound and extensive a foundation in the theory and practice of chemical science as their time and abilities will allow, rather than they should be *forced prematurely*'—the italics are mine—'into the preparation of a new series of homologous compounds, or the investigation of some special reaction, or of some possible new colouring matter, though such work might doubtless lead to publication.' We must also all cordially agree with him that the aim should be, as he tells us his has been, 'to prepare a young man by a careful and fairly complete general training to fill with intelligence and success a post either as teacher or industrial chemist, rather than to turn out mere specialists, who, placed under

other conditions than those to which they have been accustomed, are unable to get out of the narrow groove in which they have been trained.' If it were necessary to show that Sir Henry Roscoe is a believer in research in its proper place, ample proof would be afforded by his statement, 'that, far from underrating the educational advantages of working at original subjects, he considers this sort of training of the highest and best kind, but only useful when founded upon a sound and general basis.'

But I venture to think that something has to be added in order to completely define the position of those who deplore the slight amount of original work which is being done in British laboratories. We maintain that no one can really '*fill with intelligence and success* a post either as teacher or industrial chemist' who has not been trained in the methods of research; and that, owing to the neglect of research, the majority of students are of necessity trained in a narrow groove. The true teacher and the industrial chemist are daily called upon to exercise precisely those faculties which are developed in the course of original investigation, and which it is barely possible—many would say, perhaps with justice, it is impossible—to sufficiently cultivate in any other manner. In a works the *chemist* is scarcely required as long as all goes well. The quality of the materials used or produced can be controlled by purely routine processes of analysis by the works analyst, or by well-trained laboratory boys. But things never do go well for any long period of time: difficulties are always arising; obscure points have to be investigated; and, if the manufacturer understand his business, improvements have to be effected—which cannot be done unless the conditions under which he is working be understood, as well as the character of the changes which are taking place. Investigation is therefore necessary at every step. No amount of instruction, such as is ordinarily given, in the mere theory and practice of chemical science will confer the habits of mind, the acuteness of vision and resourcefulness required of an efficient chemist in a works, any more than the mere placing of the best tools in a workman's hands will make him a skilful operator.

Such being our position, we maintain that it is essential to make research an integral portion of the student's course in every college which pretends to *educate chemists.* It will not suffice occasionally to set a promising student to investigate, but a number of students, as well as the staff, must always be engaged in original work: in fact, *an atmosphere of research must pervade the college.* It cannot be too clearly recognised that it is this which characterises and distinguishes the German schools at the present time. The student does not learn so much from the one special piece of work with which he is occupied, but a number of his fellow-students being also similarly engaged, the spirit of inquiry is rife throughout the laboratory: original literature is freely consulted, and they thus become acquainted with the methods of the old masters; vigorous discussions take place, not only in the laboratory, but also at that most useful institution, the 'Kneipe'; the appearance of each new number of the scientific periodicals is keenly welcomed;—in fact, a proper spirit of inquisitiveness is awakened and maintained, until it gradually becomes a habit. Probably there is less actual routine teaching done by the staff in the German schools than in our own. I am proud to own my indebtedness to one of them, and I can without hesitation say that I never truly realised what constituted the *science* of chemistry until I came under its influence.

But to realise the state which I have pictured—*to create an atmosphere of research in our science colleges in order that it may be possible for our students to obtain complete training in chemistry,* several things are required. In the first place, it will be necessary that the students come to them better prepared than they are at present: as a rule they are so ill-prepared that it is very difficult, if not impossible, in the time at disposal to give such preliminary instruction as is indispensable before higher work can be attempted. Their mathematical knowledge is so ill-digested that it is more often than not necessary to begin by teaching simple proportion, and they look aghast at a logarithm table. They cannot draw—so far have we advanced in our civilisation that the subject is more often than not an 'extra' in our schools. They understand a little French; but German, which may almost be called the language of modern science, is indeed an unknown tongue

to them. I do not complain of their want of knowledge of science subjects, but of the unscientific manner in which they have been trained at school, and especially of the manner in which their intellectual faculties have become deadened from want of exercise, instead of developed and sharpened. Too many have never acquired the habit of working steadily and seriously; they have not learnt to appreciate the holiness of work,[1] so that they render the office of teacher akin to that of slave-driver instead of to that of friend. What is perhaps worst is their marked inability, often amounting to downright refusal, either to take proper notice of what happens in an experiment or to draw any logical conclusion from an observation. Man is said to be a reasoning being, but my experience as an examiner and teacher would lead me to believe that this fact is altogether lost sight of by the average schoolmaster, who appears to confine himself almost exclusively to the teaching of hard dry facts, and makes no attempt to cultivate those very faculties which are supposed to characterise the human race; or he is so ill-prepared for his work that he fails to understand his duty. These are harsh words, but the evil is of such magnitude that it cannot be too plainly stated; those who, like myself, are brought full face to it fail in their duty if, when opportunity occurs, they do not take occasion to call attention to its existence.

Probably the only remedy—certainly the most effectual, and that which can be most easily applied—is the introduction of a *rational system* of practical science teaching into all our schools, whatever their grade; one effect would be that all the school subjects would of necessity soon be taught in a more scientific manner. I am not one of those who would eschew the teaching of classics, and I do not wish to see science teaching introduced into schools generally in order that the students who come to me may already have gained some knowledge of science: under existing circumstances I prefer that they shall not; but I desire its introduction because the faculty of observing and of reasoning from observation, and also from experiment, is most readily developed by the study of experimental science: this faculty, which is of such enormous practical value throughout life, being, I believe—as I have said elsewhere—left uncultivated after the most careful mathematical and literary training. No one has stated this more clearly than Charles Kingsley. We are told that, speaking to the boys at Wellington College, he said: 'The first thing for a boy to learn, after obedience and morality, is a habit of observation—a habit of using his eyes. It matters little what you use them on, provided you do use them. They say knowledge is power, and so it is—but only the knowledge which you get by observation. Many a man is very learned in books, and has read for years and years, and yet he is useless. He knows *about* all sorts of things, but he can't *do* them.' This is precisely our complaint—the average schoolboy may know a good deal *about* things, but he can't *do* them. The ordinary school system of training does not, in fact, develop the 'wits,' to use a popular and expressive term for the observing and reasoning faculties; but it is certain that the wits require training. It is because the teaching of experimental science tends to develop the wits that those among us who know its power are so anxious for its introduction. This cannot be too clearly stated, the popular view—to judge from newspaper discussions—being apparently that science is to be classed with 'extras': that it is good for those who can afford it, but can be dispensed with by those who cannot. This undoubtedly is true of the 'science' which is taught the specialist, and I fear even of much of the 'science' which is at present taught in schools: let us hope that ere long other views will prevail when the object which it is sought to gain by teaching science is made clear.

While blaming the schoolmaster for his neglect, it must not be forgotten that the teaching of sciences in schools meets with comparatively little encouragement at the hands of our examining bodies and the universities. Again, examinations are too often entrusted to those who have no educational experience, and with

[1] In my experience, the behaviour of ordinary day male students is, in this respect, particularly striking in comparison with that of female and evening students: the evening students, who come with a desire to learn, and the female students are invariably most attentive, and make the fullest use of the opportunities afforded them.

most unfortunate results: in no case, probably, is inexperience so inexcusable as in an examiner. Too often, also, the examinations are in the hands of pure specialists, who take too formal a view of their duty, and expect from boys and girls at school as much as from their own students, who are older and devote more time to the work. Such examiners are prone to discourage science by marking too severely; and as their questions govern the teaching, instruction is given in schools without due reference to educational requirements, and in a purely technical style: this, I fear, is the effect of some of the universities' local examinations.

I have it on good authority that the recent changes in the scheme of the examinations for admission at Sandhurst have forced one large school, well known for the attention paid in it to the teaching of science, to cease to give instruction in science to those of its pupils who propose to compete at these examinations, at once on their deciding to do so. Then, not only are the science scholarships at the universities few in proportion, but the great majority of students pass through their university career without being called upon to gain the slightest knowledge of physical science: yet, more often than not, the teachers are chosen from these. A large proportion become clergymen, and considering the demands upon them and the unbounded opportunities which they have of imparting useful information, there cannot be a doubt that to no other class of the community is a knowledge of natural science likely to be of more value.[1] Let us hope that the time is near when our universities will no longer be open to this reproach.[2] Whatever steps they may elect to take, it is before all things important that it be not forgotten that their main purpose must be to influence the schools, so that experimental science may be used as an educational weapon at the most appropriate time, and not when the faculties to be fashioned by it have become atrophied through neglect, as I fear is too often the case, ere the university is reached.

We must carefully guard against being satisfied with the mere introduction of one or more science subjects into the school curriculum: some of those who strenuously advocate the introduction of science teaching perhaps do not sufficiently bear this in mind. Chemistry, physics, &c., may be—and I fear are, more often than not—taught in such a way that it were better had no attempt whatever been made to teach them. I hold that it is of no use merely to set lads to prepare oxygen, &c., or to make experiments which please them in proportion as they more nearly resemble fireworks; and it is not the duty of the schoolmaster to train his boys as though they were to become chemists, any more than it is his duty to fit them to enter any other particular profession or trade: the whole of the science teaching in a school should be subservient to the one object of developing certain faculties. Unfortunately, two great difficulties stand in the way at present—viz. the want of suitable books and of a rational system of teaching science from the point of view here advocated; and the requirements of the universities and other examining bodies. Both books and examinations are of too special a character: they may suit the specialist, but do not meet educational requirements. I have already somewhat fully expressed my views on this subject in a paper read at the Educational Conference in London last year. Although much more might be said, I will only now call attention to the important service which we may render in removing these difficulties.

[1] 'I sometimes dream,' said Kingsley, 'of a day when it will be considered necessary that every candidate for ordination should be required to have passed creditably in at least one branch of physical science, if it be only to teach him the method of sound scientific thought.'

[2] I learnt with the most lively satisfaction, but a few days ago, that Dr. Percival, the late head-master of Clifton College, speaking at a meeting of Convocation at Oxford last term, said: 'If twenty years ago this university had said: from this time forward the elements of natural science shall take their place in responsions side by side with the elements of mathematics, and shall be equally obligatory, you would long ago have effected a revolution in school education.' This remark elicited some warm expressions of approval. Dr. Percival, I am sure, has the cordial approval of all science teachers, and he will earn their gratitude, and deserve that of the public at large, if he can succeed in inducing his university to take action in accordance with his enlightened views.

The reform most urgently needed, in which, as members of the community, not merely as chemists, we are all most interested, is the introduction of some system which will ensure a proper training for teachers. Engineers, lawyers, medical men, pharmacists, have severally associated themselves to found institutions which require those who desire to join the profession to obtain a certain qualification; even chemists are seeking to do this through the Institute of Chemistry. But schoolmasters, although members of what is probably the most responsible, onerous, useful, and honourable of any of the professions, have as yet neither made, nor shown any inclination to make, a united effort to ensure that all those who join their profession shall be properly qualified. Surely the time has come when the subject must receive full public attention; the country cannot much longer remain content that the education of all but those of its sons and daughters who come within the province of the School Board should be carried on without any guarantee that it is being properly conducted.

Glaring as are the faults in the existing school system, and although it rests with the universities and other teaching and examining bodies—if the public do not intervene—to prescribe a proper course of instruction for potential schoolmasters and to enforce a rational system of training all the mental faculties, we science teachers may meanwhile do much by introducing more perfect methods into our own system of teaching. The students attending our courses belong to various classes: some will become chemists, and require the highest and most complete training; others will be teachers in colleges or schools; many will occupy themselves as consulting chemists or analysts; many others will have to take charge of manufacturing operations in which a knowledge of chemistry is of more or less direct importance and value; not a few will become medical men; and a large proportion, let us hope, will be those who have no direct use for chemistry, although the knowledge will be of great service to them in many ways: among such we may include architects and builders, engineers, farmers, and even country gentlemen. Have we sufficiently considered the several requirements of all these various classes? I submit, with all due deference, that we have not! Our attention has been too exclusively directed to the training up of the future analyst; the instruction has been of too technical a character.

I know it is rank heresy to say so, but I maintain that in future far less time must be devoted to the teaching of ordinary qualitative and quantitative analysis, and that *technical instruction* as now given in these subjects must find its place later in the course. Our main object in the first instance must be to fully develop the intellectual faculties of our students; to encourage their aspirations by inculcating broad and liberal views of our science, not an infinite number of petty details. We must not merely teach them the principles and main facts of our science, but we must show them how the knowledge of those facts and principles has been gained; and they must be so drilled as to have complete command of their knowledge. The great majority will not be required to perform *ordinary* analyses, either qualitative or quantitative; it will be sufficient for them to have gained such an amount of practical experience that they thoroughly understand the principles of analysis; that they shall have learnt to appreciate the sacredness of accuracy; and that they shall have acquired sufficient manipulative skill to be able when occasion requires to carry into execution the analytical process which their text-books tell them is applicable, and even, if necessary, to modify the process to suit circumstances.

Chemistry is no longer a purely descriptive science. The study of carbon compounds and Mendeljeff's generalisation have produced a complete revolution! The faults in our present system are precisely those which have characterised the teaching of geography and history, and which are now becoming so generally recognised and condemned; in fact, no better statement of the manner in which I conceive chemistry should be taught could be given than by broadly applying to the teaching of chemistry what was said by Professor Seeley, at the International Conference on Education last year, in an important paper on the teaching of history.

The necessity for some change must, I venture to think, be patent to all thought-

ful teachers, and especially to those who are called upon to fulfil the painful duties of an examiner. The railway book-stalls have made us acquainted with 'Confessions' of all sorts, but if the 'Confessions of an Examiner' were to be written they would be far more heartrending than any. The examiner in chemistry, let him go where he will, scarcely dare ask a question to which the answer cannot be directly read out from a text-book. He will be told 'that such and such a compound is formed by the action of so and so upon so and so,' but he will usually find blank ignorance of the phrase 'by the action of,' and as to the mode of performing the operation. The examiner would, however, be bound to agree with the teacher that it is almost impossible to induce students to seek information outside the lecture-room, and except in the ordinary cram text-books, and that it is hopeless to expect them to devote attention to anything unless it will pay in a subsequent examination—in fact that the old university spirit of acquiring knowledge for its own sake is almost unknown among our science students. Herein lies one of the teacher's most serious difficulties, as he is more often than not bound to teach in a particular way, or to teach certain subjects, in entire opposition to his own views, in order to qualify his students to pass a particular examination: for example, many of our colleges now distinctly state that their courses are intended to qualify students to pass the examinations of the London University, and hence they are governed by the requirements of that university, which vary more or less as the examiners are periodically changed. The examiner, on the other hand, is often placed in a difficult position: it is clear to him that the system under which the students he is called upon to examine have been taught is a bad one: yet he feels that he has no right to set questions such as he honestly believes should direct the teaching into proper channels, because he knows that the teacher is immovable, and it is not fair to make the examinees the victims of a system for which they are not responsible. Hence, perforce, the teacher goes on teaching badly and the examiner examining badly. Difficulties of this kind are bound to make themselves felt at a transition period like the present, and will only disappear if we recognise the grave responsibility which rests upon ourselves and improve our methods of teaching and our text-books: these latter, in too many instances, are unsuited to modern requirements, and are being made worse by stereotyping, and the practice which is gradually creeping in of merely changing the date on the title page and the numeral before the word 'edition,' thus engendering the belief that the information is given up to date.

Both in teaching and examining two important changes ought forthwith to be made: our students ought at the very beginning of their career to become familiar with the use of the balance; and the imaginary distinction between so-called inorganic and organic compounds should be altogether abandoned. I do not mean that students should be taught quantitative analysis as ordinarily understood, but that instead of endeavouring to make clear to them by explanation only the meaning of terms such as equivalent, for example, we should set them to perform a few simple quantitative exercises in determining equivalents, &c. It can easily be done, and terms which otherwise long remain mythical acquire a real meaning in the student's mind. That the elements of the chemistry of carbon compounds do not find a place at a very early period in the course of instruction is one of those riddles connected with our system which it is impossible to answer. Attention was once pithily directed to the fact in my hearing by a scientific friend—not a chemist—who said he had often felt astonished that, although he had learnt a good deal of chemistry, the chemistry of the breakfast-table was practically a sealed book to him, common salt being the one object of which he felt he knew something.

I may here urge that there is one great error which we *must* avoid in the future, that of overworking our students, in the sense of obliging them to pay attention to too many subjects at a time. This is done more or less, I believe, in all our science schools, and medical students are peculiarly unfortunate in this respect. It is to some extent necessitated by the deficient preliminary education of our students; but I believe that I am justified in stating that it is also partly, perhaps mainly, due to the fact that the curriculum is too often imposed by lecturers who are directly interested in the attendance of students at their lectures. This is one of the great difficulties in the way of higher education, and the continuance of the

evil is probably in a measure due to inappreciation of what constitutes higher education and culture: neither consist in a smattering of knowledge of a variety of subjects such as is too often required at present.

The more general appreciation of the value of science undoubtedly depends to a considerable extent on improvements such as I have indicated being introduced. When such is the case, we may hope that a large number of students will enter our chemical schools, not with the intention of becoming chemists, but because it will be recognised that the training there given is of high educational value, and that a knowledge of chemistry is of distinct service in very many avocations.

We may also hope that it will be possible ere long to teach chemistry properly to medical students. Seeing that the practice of medical men largely consists in pouring chemicals into that delicately organised vessel the human body, and that the chemical changes which thereupon take place, or which normally and abnormally occur in it, are certainly not more simple than those which take place in ordinary inert vessels in our laboratories, the necessity for the medical man to have a knowledge of chemistry—and that no slight one—would appear to ordinary minds to stand to reason; that such is not generally acknowledged to be the case can only be accounted for by the fact that they never yet have been taught *chemistry*, and that the apology for chemistry which has been forced upon them has been found to be of next to no value. No proof is required that the student has ever performed a single quantitative exercise; and I have no hesitation in saying that the examinations in so-called practical chemistry, even at the London University, are beneath contempt: after more than a dozen years' experience as a teacher under the system, I can affirm that the knowledge gained is of no permanent value, and the educational discipline *nil*. Here the reform must be effected by the examining boards: it is for them to insist upon a satisfactory preliminary training, and they must so order their demands as to enforce a proper system of practical teaching; and if chemistry is to be of real service to medical men more time must be devoted to its study. Physiological chemistry is taught nowhere in our country, either at the universities or at any of our great medical schools; let us hope that the publication of works like those of Gamgee and Lauder Brunton may have some effect in calling attention to this grievous neglect of so important a subject.

Having dealt with the educational aspect of the question, let me now briefly refer to some other difficulties which seriously hinder research. It has been more or less openly stated that the teachers in our chemical schools might themselves do far more. Is this the case? I do not think so; I believe it is not the staff, in most cases, who are primarily in fault. Under our peculiar system of placing the government of science schools in the hands of those who have little, if any, experience as educationalists and little knowledge of or sympathy with science, the appointments are sometimes made without the slightest reference to capability of inciting and conducting original investigation, and without any proof having been given even of a desire to promote higher education in the only possible way—by research; nevertheless, experience shows that, as a rule, fair use is made by teachers of their opportunities. The opportunities afforded us are indeed few. In the first place, the amount of actual routine teaching we are called upon to perform is very considerable, many of us having to conduct evening as well as day classes; and the work is often of the most harassing description, owing to the want of interest displayed by the students. The assistance provided is also too often inadequate, and much which should be done by assistants is therefore thrown upon the principals. Higher work under these conditions is practically out of the question, not so much because it is impossible to snatch at intervals a few hours per week, but because the attention is so much taken up in the preparation of lectures and laboratory and tutorial teaching that it is impossible to secure that freedom of mind and concentrated attention which are essential to the successful prosecution of research. Bad, however, as is often the position of the principals, that of the junior staff is usually far worse. During official hours they are entirely occupied in tutorial work, and what little energy remains must more often than not be devoted to coaching or literary work, to supplement the too modest income which the salary attached to their official position affords. Under these circumstances, it is remarkable that so much enthusiasm should prevail among

them on the subject of research. The tradition which prevails in the German schools, that the junior staff are bound to find some time for original work, is almost unknown in this country, and too often difficulties are raised, rather than facilities afforded, when the desire is manifested: we do not, in fact, sufficiently honour the assistant as the potential professor. It has also often struck me as remarkable, and it must have struck others who understand the German system, that in this practical country we have not adopted that cheap luxury—the Privat-Docent, who costs nothing and exercises a most important function in promoting higher education. The explanation of this and many other anomalies lies in the fact that very few among us realise what a university is: a clear exposition of the Scotch and German systems would be of great value in these days of new universities and university colleges.

I believe that in most, if not all, of the German chemical schools a private research assistant is placed at the disposal of the professor. Will this ever be the case here? The want of material assistance is not only felt in this respect, however: few of our chemical schools are really efficiently equipped; most of them are seriously in want of larger and more expensive apparatus, of suitable specimens, &c.; the annual grant barely suffices for the purchase of the ordinary chemicals and the payment of unavoidable current expenses, so that, as a rule, nothing remains to meet the expenses of research work—*i.e.*, of higher education. In point of fact, nearly all of those who are engaged in research are doing so at their own expense; important assistance, for which we cannot be too thankful, is indeed received from the various research funds, but the proportion which the grants bear to the total sum expended is not large. I am sure we all recognise that each one of us is bound, according to his abilities and the opportunities he has, to add to the stock of knowledge, and that the keenest intellectual pleasure is derived therefrom; but it must not be forgotten that the results we obtain are very rarely of immediate practical value, and that as a rule *we* reap no pecuniary advantage. I venture to think, in fact, that it is remarkable that so much, not that so little, is done, and that reproach rests very lightly upon the profession in this matter. Whether our national pride will prevent our being much longer beholden to foreigners for by far the greater number of new facts in chemistry is a difficult question to answer, and must rest with the public!

The occasions on which we teachers of science subjects are able to bear witness in public are of necessity few. Deeply sensible, not only of the honour, but also of the responsibility of my position as President of this Section, I felt that it was my duty to avail myself of this opportunity. Being a teacher who is interested in teaching; being convinced of the existence of most serious faults in our educational system; feeling that the present is a most critical period: I have not hesitated to speak very freely. Some of the difficulties to which I have referred might soon disappear if science teachers generally would agree to consider them together, and I believe that it would be a very great advantage if an association for the discussion of educational questions were formed of the staffs of our science colleges throughout the country. The special difficulties which surround our science colleges, and prevent them from exercising their full share of influence upon the advancement of our national prosperity might also be removed at no distant date; but I see only one way of accomplishing this, and I fear it will hardly find favour: it is by their all becoming vested in the State. In this country we like to do things in our own way, and the objection will at once be raised that this would deprive all the colleges of their individuality, and would tend to crush originality and to stereotype teaching. If I thought so, I should never make the suggestion. But it would not, provided that complete academic freedom were secured to the staff, and each college were left to adjust itself to local requirements; efficiency would be maintained by the competition of the various colleges. Local enterprise, which has hitherto been trusted to, is clearly breaking down under the tremendous strain of modern educational requirements: some change must ere long be made.

I now pass to the consideration of a subject of special interest in this Section, which I think requires the immediate earnest attention of chemists and physicists

combined—that of *Chemical Action*. In his Presidential Address to the Association last year, Professor Lord Rayleigh made only a brief reference to chemistry, but many of us must have felt that his few remarks were pregnant with meaning, especially his reference to the importance of the principle of the dissipation of energy in relation to chemical change. A year's reflection has led me to think them of peculiar weightiness and full of prophecy. I would especially draw attention to the closing paragraph of this portion of his address: 'From the further study of electrolysis we may expect to gain improved views as to the nature of the chemical reactions, and of the forces concerned in bringing them about. I am not qualified—I wish I were—to speak to you on recent progress in general chemistry. Perhaps my feelings towards a first love may blind me, but I cannot help thinking that the next great advance, of which we have already some foreshadowing, will come on this side. And if I might, without presumption, venture a word of recommendation, it would be in favour of a more minute study of the simpler chemical phenomena.'

Chemical action may be defined as being any action of which the consequence is an alteration in molecular constitution or composition; the action may concern molecules which are of only one kind—cases of mere decomposition, of isomeric change and of polymerisation; or it may take place between dissimilar molecules—cases of combination and of interchange. Hitherto it appears to have been commonly assumed and almost universally taught *by chemists* that action takes place directly between A and B, producing AB, or between AB and CD, producing AC and BD, for example. This, at all events, is the impression which the ordinary average student gains. Our text-books do not, in fact, as a rule, deign to notice observations of such fundamental importance as those of De La Rive on the behaviour of nearly pure zinc with dilute sulphuric acid, or the later ones of Faraday ('Exp. Researches,' Series vii., 1834, 863 *et seq.*) on the insolubility of amalgamated zinc in this acid. Belief in the equation $Zn + H_2SO_4 = H_2 + ZnSO_4$ hence becomes a part of the chemist's creed, and it is generally interpreted to mean that zinc *will* dissolve in sulphuric acid, forming zinc sulphate, not, as should be the case, that *when* zinc dissolves in sulphuric acid, zinc sulphate, &c., are produced. In studying the chemistry of carbon compounds, we become acquainted with a large number of instances in which a more or less minute quantity of a substance is capable of inducing change in the body or bodies with which it is associated without apparently itself being altered. The polymerisation of a number of cyanogen compounds and of aldehydes, the 'condensation' of ketonic compounds and the hydrolysis of carbohydrates are cases in point; but so little has been done to ascertain the nature of the influence of the contact-substance, or *catalyst*, as I would term it, the main object in view being the study of the product of the reaction, that the importance of the catalyst is not duly appreciated. Recent discoveries, however—more particularly Mr. H. B. Dixon's invaluable investigation on conditions of chemical change in gases, and the experiments of Mr. Cowper with chlorine and various metals, and of Mr. Baker on the combustion of carbon and phosphorus—must have given a rude shock, from which it can never recover, to the belief in the assumed simplicity of chemical change. The inference which I think may fairly be drawn from Mr. Baker's observations—that *pure* carbon and phosphorus are incombustible in *pure* oxygen—is indeed startling, and his experiments must do much to favour that 'more minute study of the simpler chemical phenomena' so pertinently advocated by Lord Rayleigh.

But if it be a logical conclusion from the cases now known to us, that chemical action is not possible between any two substances other than elementary atoms, and that the presence of a third is necessary, what is the function of the third body—the catalyst, and what must be its character with reference to one or both of the two primary agents? In the discussion which took place at the Chemical Society after the reading of Mr. Baker's paper, I ventured to define chemical action as *reversed electrolysis*, stating that in any case in which chemical action was to take place it was essential that the system operated upon should contain a material of the nature of an electrolyte ('Chem. Soc. Proc.' 1885, p. 40). In short, I believe that the conditions which obtain in any voltaic element are those which must be

fulfilled in every case of chemical action. There is nothing new in this; in fact, it practically was stated by Faraday in 1834 ('Experimental Researches in Electricity,' Series vii. §§ 858, 859[1]); and had due heed been given to Faraday's teachings we should scarcely now be so ignorant as we are of the conditions of chemical change.

The questions—What is Electrolysis? What is an Electrotyte? are all-important to the chemist, if my contention be accepted. Moreover, the consideration of chemical action from this point of view almost of necessity obliges us also to consider what it is that constitutes chemical affinity. I will not presume to offer any opinion on this subject; but I would recall attention to the prominence which so great an authority as Helmholtz gave in the last Faraday Lecture ('Chem. Soc. Trans.,' 1881, 277) to the view held by Faraday, and which is so definitely stated in a passage in his 'Experimental Researches'[2] (Series viii. 918, also 850 and 869).

Helmholtz used the words: 'I think the facts leave no doubt that the very mightiest among the chemical forces are of electric origin. The atoms cling to their electric charges, and opposite electric charges cling to each other; but I do not suppose that other molecular forces are excluded, working directly from atom to atom.' In the passages which immediately follow, this physicist then makes several statements of extreme importance, which directly bear upon the subject I desire to discuss, and which, therefore, I quote.[3]

[1] 'Those bodies which, being interposed between the metals of the voltaic pile, render it active, *are all of them electrolytes,* and it cannot but press upon the attention of everyone engaged in considering this subject, that in those bodies (so essential to the pile) decomposition and the transmission of a current are so intimately connected that one cannot happen without the other. If, then, a voltaic trough have its extremities connected by a body capable of being decomposed, as water, we shall have a continuous current through the apparatus; and whilst it remains in this state we may look at the part where the acid is acting upon the plates and that where the current is acting upon the water as the reciprocals of each other. In both parts we have the two conditions, *inseparable in such bodies as these,* namely, the passing of a current and decomposition; *and this is as true of the cells in the battery as of the water-cell*; for no voltaic battery has as yet been constructed in which the chemical action is only that of combination: *decomposition is always included,* and is, I believe, an essential chemical part.

'But the difference in the two parts of the connected battery—that is, the decomposition or experimental cell and the acting cells—is simply this: in the former we urge the current through, but it, apparently of necessity, is accompanied by decomposition; in the latter we cause decompositions by ordinary chemical actions (*which are, however, themselves electrical*), and, as a consequence, have the electrical current; and as the decomposition dependent upon the current is definite in the former case, so is the current associated with the decomposition also definite in the latter.'

[2] 'All the facts show us that that power commonly called chemical affinity can be communicated to a distance through the metals and certain forms of carbon; that the electric current is only another form of the forces of chemical affinity; that its power is in proportion to the chemical affinities producing it; that when it is deficient in force it may be helped by calling in chemical aid, the want in the former being made up by an equivalent of the latter; that, in other words, *the forces termed chemical affinity and electricity are one and the same.*'

[3] 'Several of our leading chemists have lately begun to distinguish two classes of compounds—viz., molecular aggregates and typical compounds, the latter being united by atomic affinities, the former not. Electrolytes belong to the latter class. If we conclude from the facts that every unit of affinity is charged with one equivalent either of positive or of negative electricity, they can form compounds, being electrically neutral, only if every unit charged positively unites under the influence of a mighty electric attraction with another unit charged negatively. You see that this ought to produce compounds in which every unit of affinity of every atom is connected with one, and only one, other unit of another atom. This, as you will see immediately, is the modern chemical theory of quantivalence, comprising all the saturated compounds. The fact that even elementary substances, with few exceptions, have molecules composed of two atoms makes it probable that even in these cases electric neutralisation is produced by the combination of two atoms, each

The interpretation of Faraday's law of electrolysis, which Helmholtz has brought under the notice of chemists, is of the most definite and far-reaching character. Does it, however, at all events in the form in which he has put it forward, accord sufficiently with the facts as these present themselves to the chemist's mind? All will recognise that the chemical changes effected by a current in a series of electrolytic cells are equivalent to those which take place within the voltaic cells wherein the current is generated; but in neither case is the action of a simple character: in both a variety of chemical changes takes place, the precise character of which is but imperfectly understood, and we are unable to assign numerical values, either in terms of heat or electrical units, to most of the *separate* changes. Moreover, many compounds are not electrolytes, while others which are regarded by the chemist as their analogues are very readily decomposed by a current of low E.M.F., although no great difference is to be observed in their 'heats of formation;' liquid hydrogen chloride on the one hand, and fused silver chloride on the other, may he cited as examples. Again, how are we to interpret on this theory such changes as that involved in the conversion of stannic into stannous chloride? The former, I suppose, is to be regarded as consisting of an atom of quadrivalent tin charged with four units of, say, positive electricity, and of four atoms of univalent chlorine, each carrying a unit charge of negative electricity; on withdrawal of two of the chlorine atoms, the residual $SnCl_2$ will have two free unit charges of positive electricity. We know that when the temperature is sufficiently lowered two such residues unite, forming Sn_2Cl_4, and it is not improbable that crystalline stannous chloride represents a still later stage of condensation. Is this compatible with the theory? That cases of this kind are contemplated would appear from the reference to 'unsaturated compounds with an even number of unconnected units of affinity,' which we are told may be charged with equal equivalents of opposite electricity; and also from the allusion to the existence of molecules of elementary substances composed of two atoms. It is more than probable that these anomalies would disappear on fuller statement of his views by the author of the theory: I have ventured to call attention to them in the hope of eliciting such statement.

Helmholtz tells us that electrolytes belong to the class of typical compounds, the constituents of which are united by 'atomic affinities,' not to the class of

charged with its full electric equivalent, not by neutralisation of every single unit of affinity. Unsaturated compounds with an even number of unconnected units of affinity offer no objection to such an hypothesis: they may be charged with equal equivalents of opposite electricity. Unsaturated compounds with one unconnected unit, existing only at high temperatures, may be explained as dissociated by intense molecular motion of heat, in spite of their electric attractions But there remains one single instance of a compound which, according to the law of Avogadro, must be considered as unsaturated even at the lowest temperature—namely, nitric oxide (NO), a substance offering several very uncommon peculiarities, the behaviour of which will be perhaps explained by future researches.' The popular mistake is here made of assuming that elementary substances, with few exceptions, have molecules composed of two atoms. We now know considerably over seventy elements, but of these the molecular weights in the *gaseous* state of only thirteen have been satisfactorily determined. The gaseous elements hydrogen, oxygen, nitrogen and chlorine, and also bromine, iodine and tellurium, have diatomic molecules; phosphorus and arsenic have tetratomic molecules; those of sulphur are hexatomic, and selenium molecules are probably of similar constitution, but more readily broken down than those of sulphur; lastly, cadmium and mercury molecules are monatomic. It is more than probable that carbon, and also silicon and boron form highly complex molecules. Of the remaining undetermined elements, the greater number are metals, and it is not unreasonable to assume that many of these will be found to resemble cadmium and mercury in molecular composition. It is clear, however, that at present we have no right to say that the elementary molecules are, as a rule, diatomic. It would assist in removing this error if chemists would consistently place *after* the symbol the numeral indicating the 'atomicity' of the elementary molecule—thus, Hg_1, Cd_1, O_2; and if in all cases when a numeral is absent, or is placed *before* the symbol, it were understood that advisedly no indication of the molecular state is afforded.

'molecular aggregates.' Is this the fact? Before chemists can accept this conclusion many difficulties must be removed which appear to surround the question. In the first place, it is in the highest degree remarkable that, with the one single exception of *liquefied* ammonia, *no known binary hydride is in the liquid state an electrolyte*: liquid hydrogen chloride, bromide and iodide, for example, withstanding an E.M.F. of over 8,000 volts (8,040 De La Rue cells: Bleekrode). Water, again, according to Kohlrausch's most recent determinations, has an almost infinite resistance. Yet a mixture of hydrogen chloride and water readily conducts, and is electrolysed; an aqueous solution of sulphuric acid behaves similarly, although the acid itself has a very high resistance.[1] Very many similar examples might be quoted, but it is well known that aqueous solutions generally conduct more or less perfectly, and are electrolysed.[2]

The current belief among physicists would appear to be that the dissolved electrolyte—the acid or the salt—is almost exclusively primarily decomposed (Wiedemann, 'Elektricität,' 1883, ii. 924). We are commonly told that sulphuric acid is added to water to *make it conduct*, but the chemist desires to know why the solution becomes conducting. It may be that in all cases the 'typical compound' is the actual electrolyte—*i.e.* the body decomposed by the electric current—*but the action only takes place when the typical compounds are conjoined and form the molecular aggregate*, for it is an undoubted fact that HCl and H_2SO_4 dissolve in water, forming 'hydrates.' This production of an 'electrolytical system' from dielectrics is, I venture to think, *the* important question for chemists to consider. I do not believe that we shall be able to state the exact conditions under which chemical change will take place until a satisfactory solution has been found.

F. Kohlrausch ('Pogg. Ann.' 1876, 159, 233) has shown that, on adding sulphuric acid to water, the electric conductivity increases very rapidly until when about 30 per cent. of acid is present a maximum (6,914) is attained; conductivity then diminishes almost as rapidly, and a minimum (913) is reached when the concentration corresponds with that of a monohydrate (H_2SO_4,OH_2); from this point conductivity increases somewhat (to 1,031 at 92·1 per cent. H_2SO_4), and then again falls, and is probably zero for the pure acid; on adding sulphuric anhydride to the acid conductivity again increases. Solutions of other acids and of a number of salts—chiefly deliquescent and very soluble salts—also exhibit maximum conductivity at particular degrees of concentration. In no other case has the existence of two maxima, such as are observed in solutions of sulphuric acid, been established; but probably this is because the experiments either have not been, or cannot well be, carried out with pure substances or very concentrated solutions. Solutions of less soluble salts increase in conductivity as the amount of salt dissolved increases.

Kohlrausch has suggested, as an explanation of the influence of the 'solvent' on the conductivity of an 'electrolyte,' that in a solution the ions which are being transferred electrolytically come less frequently into collision than would be the case in the pure substance. There is therefore less opportunity for the formation of new molecules, and the ions are able to travel farther before entering into combination.

Regarding the question from a chemist's point of view, however, I cannot help thinking that this explanation is scarcely satisfactory or sufficient; and I cannot

[1] It is more than probable that the most nearly pure sulphuric acid which can be obtained is not homogeneous, but is at least a mixture of H_2SO_4,$H_2S_2O_7$ and 'hydrated compounds' in proportions depending on the temperature, and hence that (pure) sulphuric acid, H_2SO_4, like water, would behave as a dielectric.

[2] On the other hand, it is remarkable that, whereas liquified ammonia may be electrolysed, an aqueous solution of ammonia is a most imperfect conductor (Faraday, F. Kohlrausch), although solutions of ammonium salts compare favourably in conductivity with corresponding sodium and potassium salts. This fact serves *somewhat* to allay the suspicion that Bleekrode did not take sufficient precautions to dry the ammonia; but his result cannot, I think, be accepted as final, on account of the relatively high E.M.F. required, and the repetition of the experiment with every precaution to ensure purity of the gas is most important. Faraday regarded the decomposition of ammonia on electrolysis of its solution as merely the result of secondary action.

resist the feeling that the production of electrolytically conducting solutions from dielectrics is in some manner dependent upon the occurrence of chemical change. If the composition of the solutions of maximum conductivity be calculated,[1] it will be seen that they contain but a limited number of water molecules; thus the solution of sulphuric acid of maximum conductivity (at 18°) contains 30·4 per cent. of acid, and therefore has the composition $H_2SO_4 : 12·4\ H_2O$ (approximately); for nitric acid the ratio is 1 : 8; for acetic acid it is about 1 : 17. Now, it is highly remarkable that the solutions of maximum electric conductivity are also very nearly those in the formation of which nearly the maximum amount of heat is developed; this will at once be obvious on comparison of the curves given by Thomsen ('Thermochemische Untersuchungen' vol. iii.), and by Kohlrausch. In the chemist's experience, the point of maximum heat development is usually near to the point of maximum chemical change, and I think, therefore, that we are justified in concluding that, even if electrical conductivity be not a maximum at a particular concentration on account of the presence of a particular hydrate (belonging to the class of molecular aggregates) in maximum amount, at all events the 'structure' of the system is especially favourable, and the 'chemical influence' exerted by the one set of molecules upon the other is at a maximum at the point of maximum conductivity. The fact that the amount of sulphuric acid required to form a solution of maximum conductivity increases with temperature—

Temp.	0°	10°	20°	30°	40°	50°	60°	70°
Per cent.	30·2	30·9	31·7	32·5	33·5	34·1	34·5	35·4

and also the fact that the maxima and minima of conductivity tend to become obliterated with rise of temperature (Kohlrausch), are both in accordance with the view that conductivity is in some way dependent upon chemical composition, as the effect of rise of temperature would be to cause the dissociation of hydrates such as I have referred to. The increase in conductivity of aqueous solutions with rise of temperature would appear to be against the view here put forward; but it is probable that this may be largely due to diminution in viscosity and increase in the rate of diffusion.

Our knowledge of the binary metallic compounds, which are generally admitted to be electrolytes *per se*, also affords evidence, I think, of an intimate relation between chemical constitution and 'electrolysability.' It has been pointed out (comp. L. Meyer, 'Theorien d. mod. Chemie,' 4th ed. p. 554) that, whereas all the metallic chlorides and analogous compounds which cannot be electrolysed are easily-volatile bodies, the electrolysable metallic chlorides, &c., are fusible only at high temperatures. A careful discussion of the various known cases does not, however, justify the conclusion that decomposition takes place, or not, according as the temperature at which the body assumes the liquid state—and at which, therefore, there is full opportunity given for electrolysis to take place—is high or low, especially as recent observations show that electrolysis may take place prior to fusion. But it is especially noteworthy that many of the chlorides, &c. which are electrolytes undoubtedly contain more than a single atom of metal in their molecules; indeed, after careful consideration of the evidence, I am inclined to go so far as to put forward the hypothesis *that among metallic compounds only those are electrolytes which contain more than a single atom of metal in their molecules.* No difficulty

[1] Formula	Formula weight	Percentage in solution of max. cond.	Composition in approximate mol. ratios	Conductivity
HNO_3	63	29·7	1 : 8	7330
HCl	36·4	18·3	1 : 9	7174
H_2SO_4	98	30·4	1 : 12·4	6914
H_3PO_4	98	46·8	1 : 6	1962
$C_2H_4O_2$	60	16·6	1 : 17	15·2
KOH	56	28·1	1 : 8	5995
NaOH	40	15·2	1 : 12·7	3276

will be felt in granting this of cuprous and stannous chlorides, and even of cadmium, lead, silver and zinc chlorides; but opinions will differ as regards the metals of the alkalies and alkaline earths.[1] Assuming the constitution of metallic electrolytes to be such as I have suggested, it is not improbable that on electrolysis a part only of the metal is determined to the one pole, the remainder being transferred along with the negative radical to the opposite pole. Hittorf, indeed, has already put forward this view in explanation of the remarkable results he obtained on determining the extent of transfer of the ions in aqueous and alcoholic solutions of the chloride and iodide of cadmium and zinc.

Again, an argument in favour of a connexion between chemical constitution and electrical conductivity is the fact that carbon, sulphur, selenium and *phosphorus* each exist in conducting and non-conducting modifications, as it can scarcely be doubted that the so-called allotropic modifications of these elements are differently constituted.

It appears, as I have already said, to be the current belief that when aqueous solutions are submitted to electrolysis, as a rule, the dissolved substance, and not the water, is the actual electrolyte. Without reference to the question I have raised as to the constitution of an electrolyte, it appears at least doubtful whether this view can be justified by appeal to known facts; at all events, I have failed to find satisfactory evidence that such is the case. Moreover, as sulphuric anhydride dissolves in water with considerable development of heat, it would appear that more work has to be done to separate hydrogen from sulphuric acid than to separate it from water; on this account we might expect that the water rather than the acid would be decomposed. Are not perhaps both affected according to the proportions in which they are present? The marked variation in the extent to which the negative ion is transferred to the positive pole, as observed by Hittorf, when solutions of different degrees of concentration are electrolysed, would appear to support this view. The difference in the products, according as dilute or very concentrated solutions of sulphuric acid are used, may also be cited as an argument that the chemical changes effected vary with the concentration; but, on the other hand, it is quite possible that the observed differences may result from the occurrence of purely secondary changes. Ostwald has recently put forward the view that one *or more* of the hydrogen atoms of certain acids are split off according to the concentration of the solution.

I call attention to this because I conceive that it has a most important bearing on the discussion of the nature of the chemical changes which occur during the dissolution of metals. Formerly it was said that, when zinc acts upon dilute sulphuric acid, the zinc displaces the hydrogen of the water and the resulting zinc oxide dissolves in the acid, forming zinc sulphate; the modern explanation advocated by most chemists has been that the metal directly displaces the hydrogen of the acid: in fact, that this is the nature of the change whenever an acid is acted upon by a metal. If in a solution of sulphuric acid, of whatever strength, the acid be the actual electrolyte, I imagine that we are right in accepting this modern view; but if the water be the electrolyte, we must, to be consistent, return to the view that the oxide—more probably in most cases the hydroxide—is the primary product. And if it can be

[1] We may regard as evidence in support of this explanation the fact that neither beryllium chloride, which fuses at 600°, nor mercuric chloride, is an electrolyte, as both of these, at temperatures not far removed from their boiling-points, exhibit the simplest possible molecular composition. It should be pointed out, however, that Nilson and Patterson found it possible to determine the density of beryllium chloride gas at a temperature 100°–150° below the melting-point found by Carnelly; but they were not able to say that fusion took place. Clarke's recent interesting observations on mercuric chloride and iodide do not, I think, suffice to prove that these compounds are electrolytes; it is more than probable that electrolysis is preceded by the formation of mercurous compounds. Even an aqueous solution of mercuric chloride does not conduct appreciably better than water (Buff). I should perhaps add that the mere presence of more than a single atom of metal in the molecule does not, I believe, alone constitute the compound an electrolyte; much depends probably both on the nature of the metal and on the structure of the molecule.

shown that during electrolysis both water and acid, according to circumstances—concentration, E. M. F., &c.—undergo change, it will be necessary to teach that in a similar manner the action of metals on acids is no less complex. Our views on the action of metals on concentrated sulphuric acid and on solutions of nitric acid of various strength must also materially depend on the interpretation of the behaviour of these acids on electrolysis with varying electromotive forces.

Having thus fully explained why I venture to think that Helmholtz's definition that 'electrolytes belong to the class of typical compounds, not to that of molecular aggregates,' is somewhat open to question, it now becomes necessary to make some slight reference to the constitution of these so-called molecular aggregates. Although opinions differ widely as to the definition to be given of a typical or atomic compound, and of a molecular compound or aggregate, the majority of chemists appear to agree that we must recognise the existence of two distinct classes of compounds. Professor Williamson, in his address to this Section at the York meeting (1881), entered at length into the discussion of this question, and in very forcible terms objected to the recognition of molecular combination as something different from atomic combinations; in this I, in the main, agree most fully with him. He further said that he had been led to doubt whether we have any grounds for assigning any limits whatever to atomic values, and he adduced a number of cases which, in his opinion, afforded illustration of a capability of elements to assume greater atomic values by combining with both negative and positive atoms than with atoms of one kind only; for example, he cited the compounds K_2CuCl_4 and K_2HgCl_4 as proof that copper and mercury may assume hexad functions; the compound K_2AgI_3 as an illustration that silver may act as a pentad; and the compounds $KAsF_6$ and K_2AsF_7 were regarded by him as evidence of the heptadicity and nonadicity of arsenic.

I have long been of opinion that the experimental investigation of this question is of great importance, and I believe that it must ere long attract the attention it deserves. The problem will be solved, not by discussions on the fertile theme of valency, but by determining the structure—the constitution—of bodies such as were referred to by Professor Williamson.

My own view on the question is a very decided one. So far as the mere definition of valency is concerned, I entirely agree with Lossen; and, as I have said, I hold with Prof. Williamson that in all compounds the constituents are held together by atomic affinities, and atomic affinities only, but I believe that the formation of so-called molecular compounds is mainly due to peculiarities inherent more especially in the negative elements—*i.e.*, the non-metals and metalloids, and not in the positive elements—the metals; in other words, to the fact that, as was first pointed out, I believe, by Lothar Meyer, the negative elements tend to exhibit a higher valency towards each other than towards positive elements. The view I take, then, is, that in the majority of so-called molecular compounds the parent molecules are preserved intact in the sense in which a hydrocarbon radical, such as ethyl, is preserved intact in an ethyl compound, being held together by the 'surplus affinity' of the negative elements. Thus I would represent the compounds K_2CuCl_4 and K_2HgCl_4 as containing copper and mercury of the same valency as the metal in the parent chloride, and regard them as compounds of the radicals $(CuCl_2)$, $(HgCl_2)$ and (KCl); a view which may be expressed by the formulæ

$$Cu\begin{matrix}Cl\,.\,ClK\\Cl\,.\,ClK\end{matrix}\qquad Hg\begin{matrix}Cl\,.\,ClK\\Cl\,.\,ClK\end{matrix}$$

The arsenic compounds referred to may be similarly represented

$$F_4AsF\,.\,FK\qquad F_3As\begin{matrix}F\,.\,FK\\F\,.\,FK\end{matrix}$$

We do not hesitate to attribute to the so-called double cyanides this order of structure, without in any way supposing that the metal changes in valency. Evidence that the 'constituent radicals exist unchanged in molecular compounds' is afforded by facts such as that ferrous and potassium chlorides, for example, form a compound which obviously is still ferrous, being of a green colour, which would

hardly be the case if the valency of the iron were increased; and that in like manner the compounds formed from stannous chloride manifest all the properties of stannous derivatives.

Whatever be the nature of chemical affinity, it is difficult to resist the conclusion that the 'charge' of a negative radical especially is rarely, if ever, given up all at once; that its affinity is at once exhausted. It would also appear that the amount of residual charge—of surplus affinity—possessed by a radical after combination with others depends both on its own nature and that of the radical or radicals with which it becomes associated. Differences such as are observed in the composition and stability of the hydrates of the salts of an acid—the sulphates, for example—clearly point to this. Other illustrations are afforded by the manner in which chlorhydric acid yields chlorhydrates of some metals and chlorides of others.[1]

It is noteworthy, however, that often those elements which from the ordinary point of view are regarded as possessed of feeble affinities are those which manifest the greatest tendency to form molecular compounds. Thus, it is commonly held that, of the three elements, chlorine, bromine and iodine, chlorine has the highest and iodine the lowest affinity, and this view accords well with the recent observations of V. Meyer on the relative stability of their diatomic molecules at high temperatures; but nevertheless we find that the compound which HI forms with PH_3 is far more stable than that of HBr or HCl with this gas; and it is well known that mercuric *iodide* has a much greater affinity for other iodides than have mercuric bromide and chloride for the corresponding bromides and chlorides.[2]

The recognition of the peculiarity in the negative elements to which I would attribute the formation of molecular compounds must, I think, exercise an important influence in stimulating and directing the investigation of these compounds and of compounds other than those of carbon; in the near future the determination of the structure of such compounds should occupy an important share of the chemist's attention. It will perhaps afford a clue in not a few cases which are not altogether satisfactorily interpreted in accordance with the popular view of valency. I may instance the formation of (?) polymeric metaphosphates, of complex series of silicates and tungstates, and of compounds of hydrocarbons with trinitrophenol. It may even serve to explain some of the peculiarities of the more complex carbohydrates.

It is one of the most clearly established of the 'laws of substitution' in carbon compounds that negative radicals tend to accumulate: numerous instances are afforded by the behaviour of paraffinoid compounds with chlorine, bromine and oxidising agents, and by that of unsaturated paraffinoid compounds when combining with hydrogen bromide and iodide. The special affinity of negative elements for negative is not improbably the cause of this accumulation. A similar explanation may perhaps be given of some of the peculiarities which are manifested by benzenoid compounds.

I would even venture to suggest that in electrolysing solutions the friction arising from the attraction of the ions for each other is perhaps diminished, not by

[1] The name chlorhydric acid is here applied to the compound $HCl(OH_2)_x$—probably $x=1$—which, according to Thomsen, is present in an aqueous solution of hydrogen chloride. It would be an advantage if we ceased to speak of HF, HCl, HBr, HI, as acids, and always termed them hydrogen fluoride, chloride, bromide and iodide respectively. The names hydric chloride, bromide, &c., might with equal advantage be altogether abandoned; hydrochloric acid is objectionable, as suggesting a relation to chloric acid. The names fluor-, chlor-, brom- and iodhydric, as applied to the *acids* present in aqueous solutions of the hydrides, are especially appropriate as indicating that they are compounds containing the radical water—that they are hydrates: indeed, it would be well to restrict the use of hydric and hydro- to bodies of this kind, and to speak of hydrides as hydri-, not as hydro-, derivatives. It would then be possible to give comparatively simple names even to complex hydrates.

[2] Thomsen gives the values in heat units as—

$$\begin{aligned} HgCl_2,2KClAq &= -1380 \\ HgBr_2,2KBrAq &= 1640 \\ HgI_2,2KIAq &= 3450 \\ HgCy_2,2KCyAq &= 8830 \end{aligned}$$

the mere mechanical interposition of the *neutral* molecules of the solvent—in the manner suggested by Kohlrausch—but by the actual attraction exercised by these molecules upon the negative ion in virtue of the affinities of the negative radicals.

One result of increased attention being paid to the investigation of problems such as I have indicated will probably be that we shall be called upon to abandon some even of our most cherished notions. I would suggest, for example, that it may become necessary to regard nitrogen peroxide not as a mixed anhydride of nitrous and nitric acids, but as a compound of two NO_2 groups; its conversion into nitrite and nitrate affords no proof of its constitution, as chlorine peroxide, ClO_2, which exhibits no tendency whatever to combine with itself, also yields both chlorite and chlorate. A greater shock may result from a conviction arising that not only carbon dioxide, but sulphur dioxide, and perhaps even sulphur trioxide, dissolve in water, forming *hydrates*—$SO_2{\cdot}OH_2$, $SO_3{\cdot}OH_2$—not *hydroxides*. In recent times, in discussing questions of this kind we have perhaps often been led to attach too much importance to the argument from analogy; it is not improbable that, especially in the case of compounds other than those of carbon, chemical change involves change in structure more frequently than we are apt to believe.

It is possible that a precise estimate of what, for want of a better name, I have spoken of as residual affinity, may sooner or later be obtained, if the view Professor Lodge has propounded in his paper 'On the Seat of the Electromotive Forces in a Voltaic Cell' be correct, that the cause of the volta effect is the *tendency to chemical action* between the bodies in contact; that, for example, chemical strain at the air-contacts is the real cause of the apparent contact-force at the junction of two metals in air. Professor Lodge, if I understand his argument, appears to assume that the air effects are in some way dependent on the presence of 'dissociated oxygen atoms.' I think this is probably an entirely unnecessary assumption; of late years, no doubt, it has been the fashion to attribute the occurrence of changes of various kinds to the presence of products of dissociation, but probably to a very unnecessary extent. Recent investigations to which I have alluded show that there are other factors of extreme importance: for example, that water must be present in order to render a mixture of carbonic oxide and oxygen explosive. Again, the observations of V. Meyer and Langer have shown that, whereas chlorine *violently attacks* platinum at low temperatures, it is *without action* upon it at temperatures between about 300° and 1,300°, but then *again begins to act* upon it, the action becoming violent at 1,600° to 1,700°. I have little doubt that the action at low temperatures is dependent upon the presence of moisture; if it were due to dissociated chlorine atoms, the action should increase with rise of temperature without break. In short, I see no reason to assume that oxygen at ordinary temperatures consists of other than diatomic molecules.[1] Assuming Professor Lodge's view to be correct, the strain exists in virtue of the attraction which the oxygen molecules exert upon the metal molecules. On this assumption, I can well understand that the method of calculation followed by Professor Lodge will not uniformly lead to satisfactory results. The 'heat of combination' is not necessarily a measure of 'affinity.' The values are in all cases algebraic sums of a series of values, scarcely one of which is known, and, as I have already pointed out, the affinities of the molecules are by no means always of the same order as the affinities of the constituent atoms: for example, in all probability, oxygen-stuff has a higher absolute affinity than sulphur-stuff; chlorine-stuff a higher absolute affinity than iodine-stuff, yet iodine and sulphur compounds, more often than not, seem to exhibit more residual affinity than chlorine and oxygen compounds. So that, from Professor Lodge's point of view, chlorine would have the higher and iodine the lower contact values; whereas, from my point of view the reverse might often be the case. I point this out because it appears to me that we here have an opportunity of testing the question experimentally, and seeing that it is possible practically to prevent chlorine from attacking metals by excluding moisture, I do not take the hopeless

[1] This conclusion would also lead me to disbelieve entirely in the explanation which Clausius has given of electrolysis.

view that Professor Lodge and others seem to hold regarding the possibility of settling the important question of pure contact *versus* chemical action by appeal to experiment. I may also point out that according to my hypothesis it is possible that the metals may exert a considerable attraction for each other, especially those having monatomic molecules:[1] many alloys are undoubtedly compounds; possibly not a few are compounds of the 'molecular aggregate' class.[2]

To return now for but a few moments to the subject of chemical change and its intimate connexion with electrical phenomena. One application I would make of the views here put forward would be to explain the superior activity of bodies in the *nascent state*, and in particular of nascent-hydrogen. Briefly stated, I believe it to consist in the fact that nascent hydrogen is hydrogen in circuit—hydrogen in electrical contact with the substance to be acted upon. The experiments of Faraday and of Grove afford the clearest evidence that in order to bring about action between hydrogen and oxygen at ordinary temperatures it is merely necessary to make them elements in a voltaic circuit. The difference in the effects produced by 'nascent hydrogen' from different sources is, I imagine, attributable to the variations in E.M.F. which necessarily attend variations in the constituent elements of the circuit.

It is not so easy, however, as yet to explain some of the changes which take place at high temperatures. Mr. Dixon's experiments have proved that a mixture of carbonic oxide and oxygen is non-explosive, but that explosion takes place if water be present, the velocity of the explosive-wave depending upon the amount of water present. When the mixture of the two gases is 'sparked,' change takes place, but only in the path of the discharge. Mr. Dixon considers 'that the carbonic oxide becomes oxidised at the expense of the water, the hydrogen *set free* then becoming reoxidised.' M. Traube, who in a series of papers has called attention to the importance of water in promoting oxidation, has suggested that the oxygen and carbonic oxide together act on the water, forming hydrogen peroxide and carbonic acid: $CO + 2OH_2 + O_2 = CO(OH)_2 + H_2O_2$; and that the peroxide then reacts with carbonic oxide to form carbonic acid: $CO + O_2H_2 = CO(OH)_2$. The carbonic acid, of course, is resolved into carbon dioxide and water ('Berichte,' 1885, p. 1890). Traube actually shows that traces of hydrogen peroxide are formed during the combustion. It appears to me that the water may exercise the same kind of action as it (or rather dilute sulphuric acid) exercises in a Grove's gas battery, and that its hydrogen does not become free in any ordinary sense. The produc-

[1] Assuming that the heat absorbed in raising the temperature of a solid is mainly expended in overcoming intermolecular attraction, the high 'atomic heat' of metals may be regarded as evidence that their molecules powerfully attract each other, and hence that their molecular composition is relatively simple; and on this view the 'atomic heat' of carbon and of a number of other non-metals and of some metalloids is low owing to the extent to which the 'affinity' of the atoms is, as it were, exhausted in the formation of their molecules. Comparison of the 'molecular heats' of chlorides and similar compounds with those of the oxides lends much support to this view, as we have reason to believe that the chlorides—which have high 'molecular heats'—are of relatively simple molecular composition, and that the oxides—which have low 'molecular heats'—are of relatively complex molecular composition. The great difference in the specific heat of ice and liquid water may perhaps be similarly explained on the assumption that ice consists of complex aggregates of H_2O molecules, whereas liquid water consists of aggregates of much simpler composition.

[2] The study of alloys from this point of view will probably furnish interesting results. It is noteworthy that the contact difference of potential of brass is less than that of copper, and much less than that of zinc, with the same solution, in all the cases quoted by Ayrton and Perry; thus—

	Zinc	Copper	Brass
Alum	−·536 volt.	−·127	−·014
Sea salt	−·565 „	−·475	−·435
Sal ammoniac	−·637 „	−·596	−·348

It is especially important to examine the copper-tin alloys, which vary in electrical conductivity in so remarkable a manner.

tion of hydrogen peroxide is not improbably due to a secondary simultaneous change.

Unlike a mixture of carbonic oxide and oxygen, a mixture of hydrogen and oxygen is violently explosive. If we assume that in both cases the reacting molecules are electrolysed by the very high E.M.F. employed, and that the atoms then combine, it is difficult to explain the difference in the results. Does it arise from the fact that hydrogen is an altogether peculiar element? Or are we to attribute it to an influence which water itself exercises upon the formation of water from hydrogen and oxygen—as in the Grove gas battery? It is noteworthy that the velocity of the explosive-wave in electrolytic gas, according to Berthelot and Vieille, is a close approximation to the mean velocity of translation of the molecules in the gaseous products of combustion calculated from the formula of Clausius (H. B. Dixon, 'Phil. Trans.,' 1884, p. 636). And this is also true of mixtures of carbonic oxide and oxygen, and of nitrous oxide and oxygen with hydrogen. May we therefore assume, as the velocity corresponds with that of the products, that the water exercises the important office of inducing change throughout the mass, and not that the hydrogen is peculiar? I am tempted here to suggest that perhaps the 'induction' observed by Bunsen and Roscoe in a mixture of chlorine and hydrogen is due to the occurrence of a change in which a something is produced which then promotes reaction between the two gases. I here assume that there would be no action between the pure gases.

If I have allowed myself to flounder in among these difficult questions, it is not because I feel that I am justified in speaking with authority, but in the hope that I may be the 'fool,' and that the 'angels' who are well able to discuss them will be led to do so without delay: for chemists are anxiously awaiting guidance on matters such as I have referred to.

Attention must, however, be directed to the study of electrical phenomena by the recent publications of Arrhenius and of Ostwald ('Journal für praktische Chemie,' 1884, **30**, 93, 225; 1885, **31**, 219, 433), and especially by the statement put forward by the latter that the rate of change under the influence of acids (in hydrolytic changes) is strictly proportional to the electrical conductivities of the acids. There cannot be a doubt that these investigations are of the very highest importance.

I trust that in the discussions which we are to have on molecular weights of liquids and solids, and on electrolysis, there may be a free exchange of opinion on some of the points here raised. My reason for selecting these subjects for discussion in this Section will have been made sufficiently clear, I imagine. Last year, in the Physical Section, the idea assumed shape which had long been latent in the minds of many members of the Association, that it is unadvisable, as a rule, to encourage the reading of abstract papers, which rarely are, or can be, discussed. Two important discussions were *introduced* by Professors Lodge and Schuster. We must all cordially agree with Professor Lodge's remarks on the importance of discussing subjects of general interest at these meetings. It appears to me, however, that even a more important work may often be accomplished if the discussion consist of a series of papers which together form a monograph of the subject. I have endeavoured to carry this idea into practice on the present occasion, and a number of friends have most kindly consented to assist. Unexpected difficulties have arisen, and probably we shall none of us succeed in doing all we might wish. I trust, however, that the Section will approve of this first attempt sufficiently to justify my successors in this chair in adopting a similar course.

I much regret that is impossible for me to attempt any review of recent work in chemistry. Not a few really important discoveries might be chronicled, and the patient industry of many who have toiled long to win results apparently insignificant should have been mentioned with high approval. A few remarks I will crave permission for regarding the general character of the work being done by chemists, and regarding that which has to be done.

Complaints are not unfrequently made in this country that a large proportion of the

published work is of little value, and that chemists are devoting themselves too exclusively to the study of carbon compounds, and especially of synthetical chemistry. We are told that investigation is running too much in a few grooves, and it is said that we are gross worshippers of formulæ. Most of these outbursts are attributable to that pardonable selfishness which consists in assigning a higher value to the particular class of work with which one happens to be engaged or interested in than to any other line of investigation; too frequently they result from want of sympathy with, if not absolute ignorance of, the scope and character of the work complained of. It must not be forgotten that chemical investigation, like other investigation, is to a large extent the work of genius; the rank and file must necessarily follow in the order of their abilities and opportunities: hence it is that we work in grooves. The attention paid to the study of carbon compounds may be more than justified both by reference to the results obtained and to the nature of the work before us: the inorganic kingdom refuses any longer to yield up her secrets—new elements—except after severe compulsion; the organic kingdom—both animal and vegetable—stands ever ready before us: little wonder, then, if problems directly bearing upon life prove the more attractive to the living. The physiologist complains that probably 95 per cent. of the solid matters of living structures are pure unknowns to us, and that the fundamental chemical changes which occur during life are entirely enshrouded in mystery. It is in order that this may no longer be the case that the study of carbon compounds is being so vigorously prosecuted: our weapons—the knowledge of synthetical processes and of chemical function—are now rapidly being sharpened, but we are yet far from ready for the attack. As to the value of the work, I believe that every fact honestly recorded is of value; an infinite number of examples might be quoted to prove this. No unprejudiced reader can but be struck also with the improvement in quality which is manifest in the majority of the investigations now published; at no time was more attention given to the discovery of all the products of the reactions studied, and to the determination of the influence of changes in the conditions. As regards our formulæ, those who look upon the outward visible form without proper knowledge of the facts symbolised, and who take no pains to appreciate the spirit in which they are conceived, are undoubtedly misled by them. The great outcome of the labours of carbon-chemists has been, however, the establishment of the doctrine of structure;[1] that doctrine has received the most powerful support from the investigation of physical properties, and it may almost, without exaggeration, be said to have been rendered visible in Abney and Festing's infrared spectrum photographs. Some of us look forward to the extension of the doctrine of structure not only to compounds generally, but even to the 'elements.' The relationships between these are in so many cases so exactly similar to those which obtain between carbon compounds, which we are persuaded differ merely in structure, that it is almost impossible to avoid such a conclusion, even in the absence of all laboratory evidence.[2]

As the field of view opens out before us, so does the vastness of the work to be accomplished become more and more apparent; and Faraday's words of 1834 may be quoted as even more appropriate than a half-century ago:

'Indeed, it is the great beauty of our science, CHEMISTRY, that advancement in it, whether in a degree great or small, instead of exhausting the subjects of research, opens the doors to further and more abundant knowledge, overflowing with beauty and utility, to those who will be at the easy personal pains of undertaking its experimental investigation.'

[1] I venture here to direct attention to an extension of the acknowledged theory of structure suggested (by myself, I may say) at the close of the discussion of the van't Hoff–La Bel hypothesis of isomerism in Miller's *Chemistry*, vol. iii. 1880 edition, p. 993. The same view was soon afterwards independently put forward by Dr. Perkin.

[2] F. Exner in a recent paper (*Monatshefte für Chemie*, 1885, p. 249) 'On a New Method of Determining the Size of Molecules,' actually put forward an hypothesis as to the structure of elements.

The following Report and Papers were read:—

1. *Report of the Committee appointed for the purpose of investigating by means of Photography the Ultra-Violet Spark Spectra emitted by Metallic Elements and their combinations under varying conditions.* See Reports, p. 276.

2. *On the Non-existence of Gaseous Nitrous Anhydride.*[1] *By* Professor WILLIAM RAMSAY, *Ph.D., and* J. TUDOR CUNDALL.

The existence or non-existence of nitrous anhydride in the state of gas cannot be decided, as attempted by Lunge, by acting on it with any reagent, for that reagent may either decompose it or react with the products of dissociation of nitrous anhydride, NO and $(N_2O_4 + NO_2)$ as if they consisted of the anhydride itself. The only true criterion of the existence or non-existence of such a substance is its vapour density. It was first conclusively proved by the author's experiments that the volume of nitric peroxide when quickly mixed with nitric oxide does not contract, clearly showing that no immediate combination ensues. Dr. Lunge has previously granted the probability of this result, but says that combination is very slow. If the combination of the products of dissociation of a dissociating body is slow, it must equally be the case that the dissociation of the dissociable substance is slow also. If this be so, the vapour density of the gas distilled from liquid nitrous anhydride should have a density 38, corresponding to the formula N_2O_3. A dark blue liquid having been prepared by the usual method, it was fractionated into a large specific gravity balloon by exhausting the balloon and attaching it to the bulb containing the liquid trioxide, certain precautions being taken to ensure that the final pressure was equal to that of the atmosphere. The result was that the first portion had the density of 22·35, while its empirical composition exactly corresponded with the formula N_2O_3. A mixture of $(N_2O_4 + NO_2)$ with NO, in such proportion as to have the composition N_2O_3 should possess, from Professor W. Gibbs' formula, the density 23·42. Supposing the gas thus weighed by us to have contained no N_2O_4 but only $NO + NO_2$, the percentage of N_2O_3 necessary to be added to raise the specific gravity to 22·35 must be 17·63.

On analysis further fractions show a constantly decreasing percentage of nitrogen and a corresponding higher density.

The argument stands thus. On mixing NO and $(N_2O_4 + NO_2)$ no contraction occurs. If combination occurs at all it must occur very slowly. On distilling a liquid containing N_2O_3 the first portion of the distillate has the empirical composition N_2O_3, but is proved by its density to contain at most 17·63 per cent. of N_2O_3, and this on the assumption, known to be false, that no N_2O_4 is present in the gaseous mixture. These facts, combined with Dr. Lunge's statement that the dissociation of nitrous anhydride is uninfluenced by rise of temperature, its behaviour thus being unique, in our opinion decide the point against the existence of gaseous nitrogen trioxide.

3. *On some Actions of a Groves's Gas-battery.* *By* Professor WILLIAM RAMSAY, *Ph.D.*

The ordinary form of gas-battery invented by Groves consists of two tubes containing oxygen and hydrogen respectively, in contact with strips of platinum coated with spongy platinum, which dip into weak sulphuric acid. On connecting the terminals of the platinums outside the liquid a current is set up, and the hydrogen and oxygen combine to form water. But as these gases are not in contact, it must be conceived that at that point where the platinum is in contact with hydrogen and liquid, the water-molecule is decomposed, its oxygen uniting with the gaseous hydrogen to form a new molecule, while the hydrogen is liberated

[1] Published in full, *Jour. Chem. Soc.*, 1885, 672.

from molecule to molecule, until free hydrogen appears at the point of contact of oxygen, platinum, and liquid in the other tube, and unites with oxygen to form again a fresh molecule of water.

Now if indigo-sulphonic acid be present in the acid, it is noticeable after a day or so that the indigo is decolorised when in contact with oxygen, being in all probability converted into isatine, but when in contact with hydrogen no action takes place. The hydrogen therefore does not reduce indigo when it is in the act of combining with oxygen.

If, on the other hand, the conducting liquid be a saturated solution of common salt, and the reacting gases chlorine and hydrogen, the indigo becomes decolorised in both tubes, the bleaching taking place from above downwards. Of course decolorisation takes place at once on admission of chlorine, but it is not until some time has elapsed that reduction by the hydrogen becomes evident. Hydrogen appears therefore to possess the power of reducing indigo when it is in the act of combining with chlorine.

Further experiments were made in order to ascertain whether other substances would comport themselves like indigo. Acid coloured with potassium permanganate was employed, and it was found that in both tubes decolorisation was to be noticed. The decolorisation of permanganate can take place only by reduction, and it must therefore be concluded that on the one hand hydrogen deprived it of its oxygen, and that on the other the action was due either to nascent oxygen, to ozone, or to hydrogen peroxide.

A blank experiment was then made; hydrogen, potassium permanganate, and platinum were left in contact, and it was found that in a few hours the permanganate became colourless. To decolorise permanganate, therefore, does not require the ordinary arrangement of a gas-battery; the feeble currents in the platinised platinum, or possibly the action of occluded hydrogen, are themselves sufficient to cause reduction and the union of the hydrogen.

A similar experiment was made with oxygen, platinum, and permanganate; after thirty-six hours the permanganate had not lost its colour. The couple appears therefore to be necessary to the formation of active oxygen, whether it be in the state of ozone or of hydrogen dioxide.

Experiments were also carried out with a solution of iodine in acidified potassium iodide, with similar results; hydrogen in contact with platinum alone reduced the iodine to hydriodic acid, but oxygen alone had no action. The solution on the oxygen side of the couple was however decolorised, although oxygen in contact with platinum had no action. With ferric chloride also the reaction was in all respects analogous. The results with indigo are therefore the only ones from which a conclusion can be drawn as to the action of the couple. The hydrogen is inactive when the couple consists of hydrogen and oxygen, but active when the couple consists of hydrogen and chlorine. Now to what cause is this difference in behaviour to be ascribed? The gaseous hydrogen is in both cases the same; the production of sodium hypochlorite on the hydrogen side is improbable, inasmuch as the formation of ozone or hydrogen dioxide on the hydrogen side is excluded when the hydrogen-oxygen couple was employed.

I would suggest as a possible explanation of this action that when a molecule of hydrogen reacts with a molecule of chlorine to form hydrogen chloride, atomic hydrogen must exist for a short interval of time. This atomic hydrogen, in the normal state, would at once combine to form molecular hydrogen, but in presence of indigo, indigo-white is produced by the union of the atomic hydrogen with indigo, as is usual when indigo is placed in contact with nascent hydrogen. But on the other hand, when a molecule of oxygen reacts with two molecules of hydrogen to form two molecules of water, it may be possible for the molecule of hydrogen to unite with the oxygen without assuming the atomic or nascent condition, and hence there is no reducing action on the indigo. But the oxygen must assume the nascent or active condition, and it is impossible to say whether its bleaching action on indigo is to be ascribed to direct action or to the formation of such intermediate products as ozone or hydrogen dioxide.

It may perhaps be objected that it is unnecessary to bring in the idea of a

status nascendi in accounting for this action. It is indeed possible that the reaction may be a direct one. Whereas the heat of formation of water is 68,360 cal., that of 2HCl.Aq is 78,640 cal., nearly 10,000 calories in excess; and the reducing action on the indigo may be ascribed to this excess. But with our present views regarding the formulæ of water and hydrogen chloride, which rest so far on a physical proof—that of the volume proportions of the gases and their compounds, it appears to me that the phenomena described present corroborative evidence of a chemical kind of the correctness of the method of writing the equations,

$$H_2 + Cl_2 = HCl + HCl, \text{ and}$$
$$2H_2 + O_2 = H_2O + H_2O.$$

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4. *On the Spontaneous Polymerisation of Volatile Hydrocarbons at the ordinary atmospheric temperature.*[1] *By* Professor Sir HENRY E. ROSCOE, *F.R.S.*

Some time ago a small quantity of a white crystalline camphor-like substance was sent to me by Mr. W. W. Staveley of West Bromwich, with the information that it had been obtained by him from the most volatile portions of the hydrocarbons, resulting from the decomposition of crude phenol at a red heat. Mr. Staveley writes, 'After standing for some weeks the greater portion of the volatile bodies, boiling from 20° to 30°, was changed by absorption of atmospheric oxygen into bodies boiling between 160° and 170°. After distilling off the lighter portion from the oxidised mixture, the residue in the retort, on cooling, solidified to a white crystalline mass.'

Examination of this product has proved that the above supposition is incorrect, and that the crystalline body is a hydrocarbon having the formula $C_{10}H_{12}$. For the purpose of purification the crude material, which had a yellow colour and was saturated with liquid, was pressed between filter-paper, and afterwards distilled in a vacuum, when it came over without decomposition at about 63° under 9 m.m. of pressure, but is found to decompose when distilled under the ordinary pressure. The hydrocarbon thus purified is perfectly colourless, crystallising in brilliant stellar clusters which melt at 32·9°. It volatilises slowly at the ordinary temperature like camphor, crystals being deposited on the upper part of the vessel containing it. Analysis gave:

	1	2	3	Mean
Carbon	90·78	90·79	90·96	90·84
Hydrogen	9·59	8·69	9·27	9·18
	100·37	99·48	100·23	100·02

The vapour density by Hofmann's method gave:

	1	2
Weight of substance . . .	0·0728 g.	0·1777 g.
Barometer reduced	760·7 m.m.	760·7 m.m.
Mercurial column	686·2 m.m.	587·0 m.m.
Volume of vapour	170·1 c.c.	206·3 c.c.
Temperature of vapour . .	100°	132°
Vapour density	4·39	4·57

The molecular formula $C_{10}H_{12}$ requires a vapour density of 4·57, and the percentage composition C = 90·9 H = 9·10. The sp. gr. of the solid hydrocarbon is 1·012 at 17°·5, the crystals sinking under water in a vacuum. It dissolves readily in petroleum spirit, ether, and alcohol, and possesses a peculiar smell resembling, but distinct from, that of camphor. On exposure to air it rapidly absorbs oxygen and is converted into a yellow resin. When heated in a vacuous tube to 180° for four hours the compound undergoes further polymerisation, and an opaque white battery mass is obtained, the solid portions of which melt with decomposition at 200° to 220°. Both solid and liquid possess a very strong odour. The hydrocarbon $C_{10}H_{12}$ at once combines with bromine, and yields a liquid bromide, which however soon

[1] *Chem. Soc. Trans.* xlvii. 669.

decomposes even in a freezing mixture, and instantly on warming yielding hydrobromic acid and a black resin. Nor could any oxidation product be obtained, the hydrocarbon being apparently completely burnt on treatment with permanganate or chromic acid. Nitric acid dissolves the crystals easily, and the addition of water to the solution throws down an amorphous nitro-compound, but the quantity obtained was insufficient for analysis.

In order to attempt to trace the genesis of this solid hydrocarbon, I had recourse to my friend Mr. Josiah Hardman, who, through his chemist, my former pupil Mr. Irwin, kindly provided me with about 200 litres of the first runnings from 240 tons of tar. This product was carefully distilled, and about 2 litres of liquid boiling below 30° was collected. Of this 200 c.c. was distilled on April 16, the whole boiling below 30°, and leaving no solid residue. On again distilling this portion, which had been at once sealed in a tube nearly filled with the liquid, about 60 c.c. boiled above 30°, and a solid crystalline residue, weighing about two grams, was left behind. This substance melted at 30°, and proved to be the hydrocarbon $C_{10}H_{12}$. One hundred c.c. of another portion of the volatile mixed hydrocarbons, obtained from a second sample of the first runnings, was distilled on March 7. It all came over between 30° and 40°, and no trace of solid crystals was noticeable. On April 13 the liquid contained a high-boiling constituent, and the residue yielded crystals of $C_{10}H_{12}$. On repeating the operation on May 5 the thermometer rose to 75°, and crystals were again obtained from the residue. The fraction of this last portion boiling from 20° to 30° was then sealed up till June 29, when it was again distilled, and from it a small quantity of the crystals was obtained. A third portion of the volatile hydrocarbon from a different tar also exhibited the same behaviour; when first distilled it all came over below 30°, and gave no indication of the presence of the solid hydrocarbon, but after standing in a sealed tube for six weeks the thermometer ran up to 65°, and the last drops of distillate yielded the crystallised substance. Hence there can be no doubt that these volatile hydrocarbons do polymerise spontaneously at the ordinary temperature, and that the solid $C_{10}H_{12}$ is probably the final product.

To identify the volatile hydrocarbon or hydrocarbons which yield the solid substance proved no easy matter. In order to separate the acetylenes the most volatile product obtained was shaken up with an ammoniacal nitrate of silver solution. The light-yellow precipitate obtained consisted mainly of the silver, composed of ethylacetylene, as its molecular weight was found to be 164·3 and 158·7 instead of 161. Portions of the mixture of hydrocarbon thus freed from the acetylene were distilled on March 4, and the whole distilled over at 30°, and showed no trace of crystals. It was then allowed to stand, as described, until April 9, when the liquid was found to yield the same solid body. Hence it appears that hydrocarbons, not acetylenes, are capable of spontaneous polymerisation. For the purpose of separation, these non-acetylene hydrocarbons were brominated. The fraction boiling below 30° yielded a large crop of a well-crystallisable bromine compound which, on analysis, proved to be butine tetrabromide, $C_4H_6Br_4$, the percentage of bromine obtained being 85·7 and 85·3 as against 85·6 required.[1] Amylene dibromide, boiling at 170°–180°, and giving a percentage of 70·0 of bromine as against 69·56, was also obtained in quantity. A liquid pentine tetrabromide, $C_5H_8Br_4$, also occurred amongst the numerous brominated derivatives. This was distilled in a vacuum, and yielded, on analysis, 81·83 per cent. of bromine as against 82·47 per cent. The sp. gr. of this bromide was 2·37. Whether, as seems not unlikely, the new crystalline hydrocarbon is derived from a hydrocarbon, C_5H_6, an isomeride of valylene, must at present remain doubtful, as the search for this body proved unsuccessful.

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5. *On some new Vanadium Compounds.*[2] *By* J. T. Brierley.

These compounds are formed by the following remarkable reaction:—If a blue solution of hypovanadic sulphate be mixed with a colourless solution of an alkaline

[1] The melting point of this tetrabromide was 116°; that of Helbing's was 99° (*L. Annalen*, 172, 281.)

[2] Printed in full in the *Journal of the Chemical Society*, 1885.

metavanadate, a dark green liquid results, and if to this a slight excess of caustic soda be added, the colour of the solution quickly changes to a deep black. From this dark-coloured solution well-defined crystalline salts can be obtained, having a purple or dark green colour and metallic lustre, in which the condition of oxidation of the metal is intermediate between the tetroxide V_2O_4 and the pentoxide V_2O_5. I have succeeded in preparing five distinct members of this group of salts, viz.:

1. A soluble sodium salt having the composition

$$2V_2O_4 . V_2O_5 . 2Na_2O + 13H_2O.$$

2. A soluble potassium salt

$$2V_2O_4 . V_2O_5 . 2K_2O + 6H_2O.$$

3. An insoluble potassium salt

$$2V_2O_4 . 4V_2O_5\ 5K_2O + H_2O.$$

4. A soluble ammonium salt

$$2V_2O_4 . 2V_2O_5\ (NH_4)_2O + 14H_2O.$$

5. An insoluble ammonium salt

$$2V_2O_4 . 4V_2O_5\ 3(NH_4)_2O + 6H_2O.$$

The soluble potassium and ammonium salts may be converted into the insoluble by boiling the solutions for some time, either alone, or much better with potassium or ammonium acetate, care being taken to keep the boiling liquid slightly alkaline. Free mixed oxides have also been obtained.

FRIDAY, SEPTEMBER 11.

The following Papers were read.—

1. *On the Essential Elements of Plants.* *By* T. Jamieson.

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2. *The Periodic Law, as illustrated by certain physical properties of Organic Compounds.*[1] *By* Professor Thos. Carnelly, *D.Sc.*

In this paper it was shown that the physical properties of the normal halogen and alkyl compounds of the hydrocarbon radicals exhibit numerous relationships, which, with one exception, are exactly similar to those which have been proved on previous occasions ('Phil. Mag.,' July 1884 and September 1885) to exist between the halogen or the alkyl compounds of the elements.

Hence the general conclusion that the physical properties of the following four classes of compounds (so far as investigated) obey the same rules:—

(1) The halogen compounds of the elements, *i.e.*, of elements with elements.

(2) The alkyl compounds of the elements, } *i.e.*, of elements with hydrocarbon radicals

(3) The halogen compounds of the hydrocarbon radicals, } *i.e.*, of elements with hydrocarbon radicals

(4) The alkyl compounds of the hydrocarbon radicals, *i.e.*, of hydrocarbon radicals with hydrocarbon radicals.

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3. *Suggestions as to the Cause of the Periodic Law and the Nature of the Chemical Elements.*[2] *By* Professor Thos. Carnelly, *D.Sc.*

The object of this paper was to show that the elements are analogous to the hydrocarbon radicals of organic chemistry, the line of argument being somewhat as follows:—

[1] *Phil. Mag.* January, 1886. [2] *Chemical News.*

As regards physical properties, the alkyl compounds (methides, ethides, propides, &c.) of the elements exhibit exactly the same relationships as the corresponding halogen compounds; hence the alkyl radicals, methyl, ethyl, propyl, &c., have the same function in these compounds as the halogens, chlorine, bromine, and iodine.

Further, the halogen or alkyl compounds of the hydrocarbon radicals exhibit exactly the same relationships as those exhibited by the corresponding compounds of the elements, even when these relationships are of the most minute and intricate kind. The relationships, in the case of both elements and hydrocarbon radicals, and for either their halogen or alkyl compounds, are strictly periodic, the several periods corresponding exactly with the series of elements usually given in tables representing the natural classification of the elements according to the Periodic Law.

It may, therefore, be inferred that the elements are built up of (at least) two primary elements, A and B, which by their combination produce a series of compounds (viz., our present elements) which are analogous to the hydrocarbon radicals.

If the above theory as to the constitution of the elements be true, the Periodic Law would follow as a matter of course, and we should therefore be able to represent the elements by some such general formula as $A_nB_{2nx+(2-x)}$, analogous to that for the hydrocarbon radicals, $C_nH_{2n+(2-x)}$, in which n = the series, and x the group to which the element or hydrocarbon radical belongs.

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4. *On the Value of the Refraction Goniometer in Chemical work. By* Dr. J. H. Gladstone, *F.R.S.*

The principal points illustrated and enforced in this communication were:

The index of refraction and the length of the spectrum are important physical properties of any substance.

The specific refraction and specific dispersion may be serviceable: 1st, in determining the purity of a substance; 2nd, in the analysis of such mixtures as ethylic and methylic alcohols; 3rd, as a guide in the investigation of organic substances; 4th, as an arbiter between rival theories as to the constitution or structure of particular chemical compounds.

The double or treble refraction equivalents of carbon, oxygen, nitrogen, sulphur, phosphorus, iron, chromium, silicon, &c. offer a specially promising field of research.

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5. *On the Refraction of Fluorine.*[1] *By* George Gladstone, *F.C.S.*

The author gave data for a more exact determination of the effect of fluorine on the refraction of light than has hitherto been published. A comparison of observations on fluor spar, cryolite, and various artificial compounds containing fluorine, showed that the refraction equivalent of this body must be considerably less than was previously supposed, and that it ranges between 0·3 and 0·8, the mean of the whole being 0·6; and that the specific refraction can, at the highest estimate, be scarcely equal to the half of that of any other substance known.

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6. *Note on some Conditions of the Development, and of the Activity, of Chlorophyll. By* Professor J. H. Gilbert, *LL.D., F.R.S.*

All who are accustomed to observe vegetation must have been struck with the great variety of shades of green which the foliage of different plants presents. Without pretending to generalise further, it may be stated that, at any rate so far as our common agricultural plants are concerned, they show somewhat characteristic shades of colour, according to the Natural Order to which they belong—the Leguminosæ

[1] Published *in extenso* in the *Phil. Mag.* December, 1885.

differing from the Gramineæ, the Cruciferæ, the Chenopodiaceæ, and so on. But the same description of plant will exhibit very characteristic differences, not only at different stages of growth, but at the same stage in different conditions of luxuriance, as affected by the external conditions of soil, season, manuring, &c., but especially under the influence of different conditions as to manuring.

The Rothamsted Field experiments have afforded ample opportunity for observations of this kind; and it has been quite evident that, in a series of comparable experiments with the same crop, depth of green colour by no means necessarily implied a finally greater amount of carbon assimilation; whilst we have long ago experimentally proved that the deeper colour was associated with relatively high percentage of nitrogen in the dry or solid substance of the herbage; and this obviously means a lower relation of carbon to nitrogen.

Mentioning these facts to Dr. W. J. Russell, who has devoted so much attention to the subject of chlorophyll, he kindly undertook to make comparative determinations of the amounts of chlorophyll in parallel specimens, in which we were to determine the percentages of dry matter and of nitrogen. Accordingly, in June 1882, during the period of active vegetation, Dr. Russell spent a day at Rothamsted for the purpose of collecting appropriate samples, which were taken from several differently manured plots of meadow-grass, wheat, barley and potatoes, respectively.

The following table gives the results of some of these experiments; namely, the percentages of nitrogen, and the relative amounts of chlorophyll, in the separated gramineous and the separated leguminous plants in the mixed herbage of grass land; in specimens of wheat grown by a purely nitrogenous manure, and by the same nitrogenous manure with a full mineral manure in addition; and in specimens of barley grown by a purely nitrogenous manure, and by a mixture of the same

RELATION BETWEEN NITROGEN ACCUMULATION, CHLOROPHYLL FORMATION, AND CARBON ASSIMILATION.

(The figures in parentheses represent determinations in the not fully dried substance).

	Nitrogen per cent. in dry substance	Relative amounts of Chlorophyll	Carbon assimilated per acre per annum	
			Actual	Difference
			lbs.	lbs.
HAY.				
Gramineæ	1·190	0·77		
Leguminosæ	2·478	2·40		
WHEAT.				
Ammonium salts only .	(1·227)	2·00	1,398	– 824
Ammonium salts and mineral manure . . .	(0·566)	1·00	2,222	
BARLEY.				
Ammonium salts only .	(1·474)	3·20	1,403	– 685
Ammonium salts and mineral manure . . .	(0·792)	1·46	2,088	

nitrogenous manure and mineral manure in addition. It is to be borne in mind that the specimens were collected while the plants were still quite green, and actively growing. It should be further explained that the amounts of chlorophyll recorded are, as stated in the table, relative and not actual; that is to say, the figures show the relative amounts for the individual members of each pair of experiments, and not the comparative amounts as between one set of experiments and another.

It will be seen in the first place that the separated leguminous herbage of hay contained a much higher percentage of nitrogen in its dry substance than the

separated gramineous herbage; and that, with the much higher percentage of nitrogen in the leguminous herbage, there was also a much higher proportion of chlorophyll. Under comparable conditions, however, the Leguminosæ eventually maintain a much higher relation of nitrogen to carbon than the Gramineæ, in other words, in their case carbon is not assimilated in so large a proportion to the nitrogen taken up.

Next, it is to be observed that the wheat plants manured with ammonium salts alone show a much higher percentage of nitrogen than those manured with the same amount of ammonium salts, but with mineral manure in addition. The high proportion of chlorophyll again goes with the high nitrogen percentage; but the last column of the table shows that, with the ammonium salts without mineral manure with the high percentage of nitrogen, and the high proportion of chlorophyll, in the dry substance of the green produce, there is eventually a very much less assimilation of carbon. The result is exactly similar in the case of the barley. The plants manured with ammonium salts alone showing the higher percentage of nitrogen, and the higher proportion of chlorophyll, but eventually a much lower assimilation of carbon.

It is evident that the chlorophyll formation has a close connection with the amount of nitrogen assimilated, but that the carbon assimilation is not in proportion to the chlorophyll formed, if there be not a sufficiency of the necessary mineral constituents available. No doubt there had been as much, or more, of both nitrogen assimilated, and chlorophyll formed, over a given area, where the mineral as well as the nitrogenous manure had been applied, the lower proportion of both in the dry matter being due to the greater assimilation of carbon and consequent greater formation of non-nitrogenous substances.

It is of interest to observe, that these results of experiments in the field are perfectly consistent with those obtained by vegetable physiologists in the laboratory; they having found that the presence of certain mineral or ash-constituents, and especially that of potassium, is essential for the assimilation of carbon, no starch being formed in the grains of chlorophyll without the aid of that substance. Sachs says, 'Potassium is as essential for the assimilating activity of chlorophyll as iron for its production.'

7. *A Plea for the Empiric Naming of Organic Compounds. By* Professor ODLING, *F.R.S.*

8. *On the Action of Sodium Alcoholates on Fumaric and Maleic Ethers.*[1] *By* Professor PURDIE, *Ph.D., B.Sc.*

In a previous research ('Chem. Soc. Journ.,' 1881) the author has shown that by the action of sodium alcoholates in alcoholic solution on the ethereal salts of fumaric acid, products are obtained which by saponification yield alkyloxysuccinic acids; thus ethoxysuccinic and butoxysuccinic acids were prepared by the action respectively of a solution of sodium ethylate on ethylic fumarate, and of sodium butylate on butylic fumarate. The object of the present investigation is to elucidate the nature of the chemical reactions concerned in the change, and to compare the etheric acids obtained from fumaric acid with the corresponding additive products procured by similar methods from maleic acid.

Action of sodium methylate on ethylic fumarate.—When a solution of sodium methylate in methylic alcohol is added to ethylic fumarate, the first product of the action is methylic fumarate, which, however, is quickly converted into methylic methoxysuccinate, an oil boiling about 220° C., not without some decomposition. The sodium methylate used converts much more than its molecular proportion of fumaric ether into the addition compound, and it appears that an intermediate compound, a methylic methoxysodosuccinate, is formed, which, however, is continuously decomposed in the presence of alcohol, exchanging

[1] *Jour. Chem. Soc.*, 1885, 855.

its sodium for the hydrogen of the latter while sodium methylate is reproduced. Methoxysuccinic acid procured by decomposition of its calcium salt with sulphuric acid is a crystalline solid melting at 101° to 103° C. Descriptions and analyses of the acid potassium salt and of the calcium and zinc salts are given. The observed conversion of ethylic fumarate into methylic fumarate by the action of sodium methylate is by no means an isolated instance of the interchange of alcoholic radicles between an ethereal salt and an alcohol, but in the instances hitherto observed the interchange is accompanied by partial saponification, as when ethylic oxalate is converted by the action of potassium methylate into potassic methylic oxalate. The author finds that in this reaction normal methylic oxalate is also produced, and that in a similar manner ethylic cinnamate is converted into methylic cinnamate; also, that if the ethylic salt is dissolved in methylic alcohol, the addition of certain salts, such as potassic carbonate, calcic chloride, and ignited borax, induces the interchange of alcoholic radicles.

The general subject of the interchange of alcoholic radicles between ethereal salts and alcohols, induced by various reagents, is being now investigated.

Action of sodium ethylate on ethylic fumarate.—This action has been previously described by the author, and ethoxysuccinic acid and several of its salts characterised. Further observations indicate that here also an intermediate sodium compound is formed, which, however, undergoes partial saponification, forming sodic ethylic ethoxysodosuccinate.

Action of sodium methylate and of sodium ethylate on ethylic maleate.—From the latter reaction no pure products could be obtained, but from the former a methoxysuccinic acid was procured, in its properties closely approximating to, if not identical with, the acid obtained from ethylic fumarate.

Action of sodium methylate on hydric methylic maleate.—As it was found that a solution of maleic anhydride in methylic alcohol could be substituted for the normal maleic ether, this solution was used to obtain the material required for the further examination of the addition products from maleic acid. Hydric methylic maleate is formed by heating maleic anhydrid with methylic alcohol, and the sodic methylic maleate, formed on the addition of sodium methylate, being soluble in the alcohol, is quickly converted into sodic methylic ethoxysodosuccinate, which by saponification yields the sodium salt of a methoxysuccinic acid. The acid, obtained as before from the calcium salt, crystallises in the same manner and has the same melting-point as the corresponding acid obtained from fumaric acid. The salts also which have been already mentioned are identical, with the exception of the zinc salts, which seem to differ slightly. Both salts crystallise with four molecular proportions of water, three of which are given off at 100°, while the remaining molecule is retained to nearly the temperature at which the substance undergoes decomposition; they appear, however, to differ in mode of crystallisation, and the salt derived from fumaric acid loses its last molecule of water of crystallisation at about 205° C., while that obtained from maleic acid does not become anhydrous till about 215° C. The high temperature required for the complete elimination of the water of crystallisation is remarkable, and an exact determination is attended with considerable difficulty, owing to the incipient decomposition of the salts at slightly higher temperatures.

Action of sodium ethylate on hydric ethylic maleate.—By the addition of sodium ethylate to a solution of maleic anhydrid in ethylic alcohol, and subsequent saponification of the product of the reaction, an ethoxysuccinic acid was obtained, the properties of which were found to be identical with those of the corresponding acid from fumaric ether. The calcium and barium salts were analysed and found to agree, as regards water of crystallisation and solubility, with the corresponding ethoxysuccinates previously obtained from fumaric ether.

The above experiments show that fumaric and maleic acids yield alkyloxysuccinic acids, which are identical with one another, or, if not identical, so closely resembling each other that their isomerism must be of the same nature as that of substances which differ only in optical and crystallographic characters. This supposition is by no means improbable in view of the fact that the malic acid prepared from fumaric acid by the action of caustic soda seems to differ from ordinary malic acid and

from Kékulé's inactive malic acid, and in view also of the discovery of Kékulé and Anschütz that fumaric acid on oxidation gives racemic acid, while maleic acid yields mesotartaric acid. On the other hand the slight differences found to exist between the zinc methoxysuccinates—the only difference observed so far between the corresponding addition products—may be due to slight impurity in one or both of the salts, a supposition not improbable, considering that the acids did not give absolutely definite melting-points.

K. Grosner has recently shown (Inaugural Dissertation, Würzburg, 1885), that the ethers of the isomeric pyrocitric acids, when treated with sodium alcoholates, yield alkyloxypyrotartaric acids; he finds, however, that itaconic and mesaconic ethers yield the same acid, and citraconic ether an acid which, though isomeric, is essentially different in its properties from the other. In view of the relation of citraconic to mesaconic acid being in so many respects similar to that subsisting between maleic and fumaric acids, these results are difficult of explanation.

The author intends, as soon as he has a sufficient quantity of material at his disposal, to investigate the optical and crystallographic characters of some of the salts of the ethoxy- or methoxysuccinic acid, obtained from the two parent acids, with the object of determining the identity or isomerism of the acids in question. He purposes also preparing alkyloxysuccionic acids direct from malic acid, so as to compare these acids, obtained from various sources, with each other, and also with the isomeric malic acids now being investigated by Anschütz. He also reserves for further study the intermediate sodium compounds to which reference has been made.

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9. *On Sulphine Salts derived from Ethylene Sulphide.* *By* Orme Masson, *M.A., D.Sc.*

Ethylene sulphide, as obtained by mixing alcoholic solutions of ethylene bromide and potassium sulphide, is a white amorphous powder, insoluble in any of the ordinary solvents, and very difficult to obtain in a state of purity. When heated to about 160° C., either by itself or with carbon disulphide in sealed tubes, it is converted in great part into the crystalline diethylene disulphide $S{<}\begin{smallmatrix}C_2H_4\\C_2H_4\end{smallmatrix}{>}S$, whose constitution is adduced from its vapour density, its reactions, and from the fact that it is also produced according to the equation

$$C_2H_4{<}\begin{smallmatrix}S\\S\end{smallmatrix}{>}Hg + Br_2C_2H_4 = C_2H_4{<}\begin{smallmatrix}S\\S\end{smallmatrix}{>}C_2H_4 + HgBr_2$$

[Crafts, *Ann. Chem. Pharm.* cxxiv. 110; cxxviii. 220; Husemann, *ibid.* cxxvi. 269.]

The author has found that this crystalline sulphide is capable of combining directly with methyl iodide to form a sulphine salt of the formula

$$S{<}\begin{smallmatrix}C_2H_4\\C_2H_4\end{smallmatrix}{>}S{<}\begin{smallmatrix}CH_3\\I\end{smallmatrix}$$

the combination taking place slowly at the ordinary temperature when the reagents are mixed in ethereal solution, and quickly when they are heated to 60°–70° in sealed tubes.

Diethylenesulphide-methyl-sulphine iodide is freely soluble in hot water, much less so in cold water, practicably insoluble in alcohol or ether. It separates from the hot aqueous solution, on cooling, in opaque white crystals which at first sight appear to be cubical, but are not truly so; and by slow evaporation of the mother liquor it is obtained in the form of transparent prismatic needles. It enters into double decomposition with soluble silver salts, producing well defined crystalline salts of the sulphine radical. Of these the *nitrate* $(C_2H_4)_2S_2(CH_3)NO_3$, and the *sulphate* $\{(C_2H_4)_2S_2CH_3\}_2SO_4 . 3H_2O$, have been examined. From the latter, by the action of barium salts, the chloride and other compounds of the sulphine radical may be prepared. The *chloride* $(C_2H_4)_2S_2CH_3Cl$, yields insoluble or sparingly soluble compounds with certain metallic chlorides. Thus with platinic chloride it gives a heavy yellow precipitate of $(C_2H_4)_2S_2CH_3Cl . PtCl_4$, insoluble in

hot or cold water, alcohol, or dilute acids; and with mercuric chloride it gives a white crystalline compound, $(C_2H_4)_2S_2CH_3Cl.\ HgCl_2$, which is soluble in hot water.

The above-mentioned salts of diethylenesulphide-methyl-sulphine undergo decomposition on heating, and yield sublimates of diethylene disulphide. The haloid salts give also the corresponding methyl compounds. In this behaviour when heated, in their method of formation, and in their general properties, they resemble the salts of trimethyl-sulphine, from which, however, they differ widely in some respects. None of the salts, for instance, are deliquescent, which is a marked property of those of trimethyl-sulphine. The platinic chloride compounds differ in composition and properties. But the most marked characteristic of the diethylenesulphide-methyl-sulphine salts is to be found in their behaviour with alkalis. Thus the sulphate treated with barium hydrate in the cold gives a precipitate of barium sulphate and a solution which is strongly alkaline (before sufficient baryta has been added to decompose all the salt), and from which the sulphate can be again obtained by neutralising with sulphuric acid and evaporating to dryness. This solution undoubtedly contains the base, $(C_2H_4)_2S_2CH_3OH$; which, however, cannot be separated, as it quickly undergoes a change on standing and is converted, by loss of the elements of water, into an oily liquid possessing a very peculiar and disagreeable smell. This oil is produced at once if the iodide or other salt be boiled with potash or even with an alkaline carbonate, which shows that diethylenesulphide-methyl-sulphine hydroxide, unlike trimethyl-sulphine hydroxide, is capable of being turned out of its compounds by the alkalis. The investigation of this oil is not yet completed.

In 1865 Dehn ('Ann. Chem. Pharm. Suppl.,' iv. 83), described the action of ethyl sulphide on ethylene bromide when these are heated together with water in sealed tubes. His main products were ethyl bromide, diethylene disulphide, and triethyl-sulphine bromide; but he also obtained small quantities of two other sulphine compounds. His method was to remove by suitable means the diethylene disulphide and ethyl bromide, to treat the remaining aqueous solution with silver oxide, and then to add excess of hydrochloric acid and fractionally precipitate with platinic chloride. By this means he obtained three distinct compounds, of which the last to come down was the triethyl-sulphine salt, $\{(C_2H_5)_3SCl\}_2PtCl_4$, which is soluble in, and can be crystallised from, hot water. The two others were obtained as yellow precipitates, insoluble in all ordinary solvents. Dehn estimated the platinum in the first of these and the platinum, carbon, and hydrogen in the second. His results led him to conclude that they were compounds of the formulæ $(C_2H_4)_2S^{vi}Cl_2.PtCl_4$ and $(C_2H_4)\ (C_2H_5)_2S^{vi}Cl_2.PtCl_4$,—what he called sulphinic salts, containing hexad sulphur, as opposed to sulphinous salts in which the sulphur is tetrad. It seems almost certain, however, judging from the method of formation, from the properties of the platinic salts themselves, and from the results of Dehn's analyses, that he was really dealing with compounds analogous to the diethylenesulphide-methyl-sulphine platinic-chloride salt described above: viz., with $\{(C_2H_4)_2S_2\}_2(C_2H_4)Cl_2.2PtCl_4$ and $(C_2H_4)_2S_2(C_2H_5)Cl.PtCl_4$. The percentages of carbon, hydrogen, and platinum, calculated from these formulæ, those calculated from Dehn's formulæ, and those found by him, agree with one another within the limits of experimental error; the chlorine and the sulphur, which differ widely, were not estimated by him. If the view here advanced be correct, then Dehn's reaction may be represented by the equations:—

(1) $2C_2H_4Br_2 + 2(C_2H_5)_2S = (C_2H_4)_2S_2 + 4C_2H_5Br.$
(2) $(C_2H_5)_2S + C_2H_5Br = (C_2H_5)_3SBr.$
(3) $(C_2H_4)_2S_2 + C_2H_5Br = (C_2H_4)_2S_2.C_2H_5Br.$
(4) $2(C_2H_4)_2S_2 + C_2H_4Br_2 = \{(C_2H_4)_2S_2\}_2.C_2H_4Br_2.$

10. *An apparently new Hydrocarbon distilled from Japanese Petroleum.* *By* Dr. Divers *and* T. Nakamura.

11. *Description of some new Crystallised Combinations of Copper, Zinc, and Iron Sulphates.* By JOHN SPILLER, *F.C.S.*

It was known that these metallic sulphates were capable of crystallising together, but the author had made experiments with the view of getting definite combinations.

In consequence of the wide differences in the degree of solubility, it was necessary to employ the zinc salt in large excess, so as to force this ingredient into the combination. Sulphate of copper being, on the other hand, much more sparingly soluble, had a tendency to separate out alone, or with at most 8 to 10 per cent. of zinc (or iron) sulphate in admixture.

A large series of well crystallised double salts had been prepared and analysed, of which the following were the most definite examples:—

$$Cu\,Fe\,(SO_4)_2 + 12\ aq.$$
$$Zn\,Fe_3(SO_4)_4 + 28\ aq.$$
$$Zn_2Fe_3(SO_4)_5 + 35\ aq.$$
$$Cu\,Zn_3(SO_4)_4 + 26\ aq.$$
$$Cu\,Zn_4(SO_4)_5 + 33\ aq.$$
$$Cu\,Zn_5(SO_4)_6 + 40\ aq.$$

The last named double salt could be obtained in magnificent pale-blue rhombs, like a tinted calc-spar, but *not* double refracting. The tri-zinc cupric sulphate had long ago been prepared by Lefort, who asserted, however, that it contained 28 molecules of water, a statement which the author believed to be incorrect, finding by his analysis that each salt introduced its own proper amount of water of crystallisation.

SATURDAY, SEPTEMBER 12.

The following Papers were read:—

1. *The Composition of Water by Volume.* By A. SCOTT, *M.A., D.Sc., F.R.S.E.*

No determinations as such of the ratio of the volumes in which oxygen and hydrogen combine to form water have been made since those of Humboldt and Gay-Lussac in 1805. The experiments of Regnault and Amagat show conclusively that neither of these gases obeys Boyle's law, their deviations being in opposite directions; hence if we admit Avogadro's law for perfect gases, it could only be by the merest chance that the true ratio would be 2 of hydrogen to 1 of oxygen. With the improved methods for preparing and measuring gases now at our command, it seemed that this important ratio ought to be redetermined, if possible on a larger scale. The quantities operated on are about 150 c.c. of oxygen and 300 c.c. of hydrogen in each case. Two experiments gave the following ratios—

$$1 : 1{\cdot}994$$

and

$$1 : 1{\cdot}9935$$

or

$$1 : 1{\cdot}9960$$

if the impurity be supposed to exist in oxygen alone.

The purity of the gases was tested by subsequent analysis, of the residue, and ·2 to ·3 c.c. of foreign gas found in 450 c.c. of gas used.

The author, however, hopes by his processes of preparing the gases to obtain them in a still higher degree of purity.

2. *Description of a new Mineral from Loch Bhruithaich, Inverness-shire. By* W. Ivison Macadam, *F.C.S., and* Thomas Wallace.

3. *Exhibition and Description of the Apparatus employed in obtaining Oxygen and Nitrogen from the Atmosphere. Description of Method used in converting atmospheric Nitrogen into Ammonia. By* Messrs. Brin Brothers.

MONDAY, SEPTEMBER 14.

The following Report and Papers were read:—

1. *Report of the Committee on Chemical Nomenclature.*

See Reports, p. 262.

2. *On Electrolysis. By* Professor Oliver J. Lodge, *D.Sc.*

See Reports, p. 723.

3. *On Helmholtz's views on Electrolysis, and on the Electrolysis of Gases. By* Professor Schuster, *F.R.S.*

The author explained some of the views expressed by Helmholtz in his recent papers on electric polarisation and electromotive force, remarking that the President of the Chemical Section had, in his opening address, already drawn attention to the bearing which these views have on chemical theories. The fundamental notion of Helmholtz consists in the assumption of a different attraction of chemical elements for positive and negative electricity. If this is admitted, the difficulties which have been felt in explaining electromotive force of contact disappear. In compound bodies like water, the hydrogen is positively electrified; the oxygen, on the other hand, is charged with negative electricity. If an electromotive force acts on the liquid, the positively charged atom is driven to the negative pole, and the oxygen to the positive pole.

This motion is called forth by any electromotive force, however small, and no work is done except that due to overcoming of the internal resistance. The positively charged hydrogen atom covers the negative electrode, but does not constitute free hydrogen. When the electromotive force is sufficiently strong, an interchange of electricity takes place between the pole and the ion, and then only can the hydrogen separate out.

A large amount of work has to be done to separate the positive charge from the hydrogen. In all decompositions where the elements separate out in a neutral state, it would seem, if these views are correct, that before decomposition an interchange of electricity must take place. Thus, for instance, when aqueous vapour is dissociated by heat, the oxygen must give up its free electricity before it can form neutral oxygen molecules. The conversion of stannic into stannous chloride, mentioned by the President, would have to be accompanied by an interchange of a negative charge on the chlorine with a positive charge on one of the atoms of tin, leaving then both neutral chlorine and neutral stannous chloride.

With respect to the question of rates at which the ions travelled, Professor Schuster thought Professor Lodge had not laid sufficient stress on the remarkable result arrived at by Kohlrausch, that in dilute aqueous solutions, and for a given intensity of current, each element had its own rate of travelling, which was independent of the other ion; thus the barium atom travelled at the same rate whether

originally combined with chlorine or iodine. This result gave a very strong support to the views from which it could be deduced, and proved conclusively the different velocities of different ions.

Finally, Professor Schuster explained his views of the electric discharge of gases, which, in his opinion, presented many analogies to the electrolytic conduction, or rather that called by Helmholtz electric convection. The peculiar phenomena surrounding the negative electrode, as well as stratifications, do not appear in the discharge through mercury vapour, and were probably due to a splitting up of the two-atomed molecules at the negative pole. Phenomena of polarisation consequently appear at the kathode, but the ordinary methods of investigating these phenomena are not available in gases. Experiments which the author hoped to perform in the next few months will decide whether in the gaseous discharge each atom carries off, as in electrolysis, the same quantity of electricity.

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4. *On the Determination of Chemical Affinity in terms of Electromotive Force. By* C. R. Alder Wright, *D.Sc., F.R.S.*

During the last eight years, the author has carried out (partly by himself, and partly in conjunction with Dr. Rennie and with Mr. C. Thompson), a lengthy series of observations on various points connected with this problem, many of the results of which have been communicated from time to time to the Physical Society of London, and published in its proceedings and in the 'Philosophical Magazine,' in a series of nine memoirs. Whilst these experiments have served to corroborate or correct various previously measured values, and to establish a number of new ones, they have as yet not sufficed to solve the entire problem, but on the contrary, rather tend to indicate that electrical measurements alone are unlikely to give any simple means of readily obtaining exact determinations of the amounts of force and energy involved in the occurrence of chemical changes, at least so far as the more deep-seated phases of these reactions are concerned.

The fundamental idea involved in the conception of the possibility of such determinations being made is due to Sir William Thomson, having been put forth by him in a paper on the Mechanical Theory of Electrolysis.[1] The reasoning involved may be simply stated as follows:—

Faraday has shown (1) that when a compound is electrolysed, the weight of substance decomposed is proportionate to the quantity of electricity passing.[2] In symbols, $n \propto q$, where n is the number of grammes decomposed, and q the quantity of electricity passed. (2) That the weight decomposed by a constant quantity of electricity is proportionate to the chemical equivalent of the substance; *i.e.* if a be the equivalent $n \propto a$. Hence, on the whole, $n \propto aq$; and hence, $n = aq \times$ constant, this constant, or 'Faraday coefficient,' being a numerical value conveniently indicated by the symbol F, just as the Joule value J indicates the somewhat analogous constant relating to mechanical work and heat. Now, suppose the passage of the current to effect no work other than chemical decomposition, and let the lowering of potential (E.M.F.) occurring between the extremities of the mass through which the current passes causing decomposition be e; then eq represents the work done: if f represent the work done by the force of chemical affinity in synthesising a gramme of the compound decomposed from the products of decomposition, the work done is also $nf = aq\text{F}f$; whence $af = \frac{e}{\text{F}}$; that is, the value of the chemical affinity per gramme equivalent of compound is measured by a value in E.M.F.

[1] *Phil. Mag.*, 1851, vol. ii. p. 429,

[2] Various experimenters have been led to believe that under certain conditions, 'conduction without electrolysis' may take place, more especially when extremely feeble currents are passed through acidulated water. The author has shown in a rigorously conducted series of experiments that the non-appearance of products of decomposition in such cases is due to causes other than exceptionality to the law of Faraday (*Phil. Mag.*, April 1881.)

In actual practice the work ultimately done by the passage of a current through an electrolyte is not solely chemical decomposition; a disturbance of the thermal equilibrium also takes place, usually heat evolution. A certain amount of heat evolution, in fact, necessarily ensues, owing to the resistance proper of the medium. In accordance with 'Joule's Law' the work done in this form is C^2Rt (where C is the current, R the resistance proper, and t the time), which may be written $e'q$, since $q = Ct$, and by Ohm's Law CR represents an E.M.F. which may be written e'. If, then, a total fall of potential of E occur, part of this, e', is due to heat evolution through resistance proper; the rest, $E - e'$, is due to other causes, viz. chemical decomposition modified by secondary actions taking place, either spontaneously in the products of electrolysis themselves, or by their causing chemical changes in the electrodes. These secondary actions are usually of such a nature as to cause as final result the production of more or less sensible heat; but generally a greater or less fraction of the energy due to these acts in the same sense as the current itself; that is, the secondary actions assist the current, and cause a less amount of lowering of potential to take place than would otherwise be the case. That portion of the energy due to these secondary changes that thus assists the current may conveniently be spoken of as *adjuvant*, and the rest as *nonadjuvant*.

With certain kinds of electrolytes and electrodes, the amount of adjuvant energy is sufficient not merely to equal the lowering of potential due to the passage of the current *per se*, but to preponderate thereover, so that a *negative* lowering of potential results as the current passes. Such cells constitute ordinary electromotors or 'voltaic circles,' and usually require no external current to start their action.

Whether an electrolytic cell be one in which an actual lowering of potential takes place during the passage of a current from an external source, or one capable of causing an increment in potential of itself without any current passing derived *ab extra*, it is invariably found that the actual potential difference subsisting when a current passes, after correction for the quantity e' due to heat evolution in consequence of resistance proper, is not a constant quantity, but varies with the degree of concentration of the solutions and the nature of the surfaces of the electrodes, and with the density of the current (ratio of current to electrode superficies). With a decomposing cell (where actual lowering of potential takes place) this corrected potential difference increases, *cæteris paribus*, with current density; and with an electromotor (where negative lowering of potential ensues) it decreases therewith; the same rule being observed throughout, that *the greater the density the greater is the amount of nonadjuvant energy due to secondary actions.* In other words, the 'counter E.M.F.' of a decomposing cell, $E - e'$, continually increases with increasing current density, constantly tending towards a limiting value attainable theoretically with an infinite current; whilst the negative counter E.M.F. (or positive E.M.F.) of a voltaic cell or electromotor is at its maximum when the current density is extremely small, and continually decreases as the current density increases.

A large number of experiments have been made (as yet unpublished) with a view of deducing for various electrolytes the limiting values of the 'counter E.M.F.s.' set up during electrolysis, the method adopted being the construction of curves with current densities and counter E.M.F.s as co-ordinates from which empirical exponential equations might be deduced leading to the evaluation of the limiting values for infinite densities. Much labour is necessarily entailed in this class of experiment in order to obtain any results of value even as approximations. The results obtained so far show that these limiting values far exceed those corresponding with the heat evolutions ensuing when the final products of the electrolytic decomposition are made to recombine so as to reproduce the compound experimented with. Thus, for example, the heat disengaged when one gramme of hydrogen and eight of oxygen (both gaseous under ordinary conditions) coalesce to form nine grammes of liquid water is close to 34,100 gramme degrees, corresponding with about 1·5 volts; but the limiting value of the counter E.M.F., $E - e'$, in this case exceeds 4 volts. On the other hand, when water is decomposed by feeble currents so that the evolved gases are absorbed or occluded by the electrodes, or are attracted thereto forming air-films over their surfaces, the values of $E - e'$ may

fall far short of 1·5 volt, being in certain cases barely appreciably greater than 0. It would thus seem that whilst the heat evolved during the condensation of 1 gramme of hydrogen and of 8 grammes of oxygen to the physical state of the gases occluded or attracted in the form of these films must jointly amount to something close to 34,100 gramme degrees at least, the energy requisite to break up water not into ordinary free oxygen and hydrogen, but into the *nascent* forms of these bodies, unmodified by subsequent coalescence or spontaneous modification must be equal to something not far short of three times that amount; whilst the total heat evolved during the subsequent modification of these elements (passage from atomic to molecular condition?) must represent at least 2·5 volts.

A large number of observations have been made (mostly published) on the relationships between the positive E.M.F.s generated in various kinds of voltaic cell when at their maximum, and the amounts of heat corresponding with the nett chemical changes ensuing between the electrolytes and electrodes. The general result of these investigations has been to show that in but few instances are the two values approximately coincident (say within a departure of $\pm 0{\cdot}1$ volt), and even in these cases very material fluctuations in the actual E.M.F. of an electromotor may be brought about by alterations in solution, strength, and plate surface nature that exert but little influence on the nett heat development. One conclusion deducible from this and other allied facts is that the seat of primary action in such cases lies at the junctions of the surfaces of the electrodes and fluids, and that the *modus operandi* of a voltaic cell is in certain respects closely akin to that of a thermo-couple or Peltier couple, consisting of two dissimilar forms of solid matter (metals, &c.) where conversion of sensible heat into current takes place, or *vice versa.* In fact the actual maximum E.M.F.s set up in such cells as those examined (mostly after Daniell's construction, *e.g.*, $Zn \mid ZnSO_4 \mid CuSO_4 \mid Cu$) are found to be conveniently represented by assigning to each given metal immersed in a given solution of one of its salts a numerical value, or *thermo-voltaic constant* (analogous to the thermo-electric values assignable to metals, &c., when used in thermo-electromotors), and adding the algebraic difference between the values for any two given pairs of metal and salt (which difference may be a positive or negative quantity) to the value in volts corresponding with the heat evolution due to the nett chemical change. According as this difference is plus or minus, the E.M.F. actually set up exceeds or falls short of the amount due to the nett chemical change. Relatively to zinc, some metals have thus in general a negative and others a positive thermo-voltaic constant assignable, no matter what the class of salt employed. The cells where the algebraic difference between the thermo-voltaic constants is positive in sign are characterised by the peculiarity that in the production of a current by them sensible heat must become converted into current energy, causing cooling of the cell; for with a large external resistance more work is done outside the cell than corresponds with the heat development due to the nett chemical change. With cells where this difference is negative in sign, the reverse holds so long as the numerical value of the difference is not greater than that corresponding with the difference in heat of formation between the two fluids surrounding the plates; the cell in this case being warmed by the passage of the current, and less external work being done than corresponds with the nett heat development due to chemical change. When, however, the numerical value of the negative algebraic difference between the thermo-voltaic constants exceeds that corresponding with the difference in heat of formation, the remarkable result ensues that the current circulates in the direction opposite to that predicable from the relative heats of formation of the fluids in the cell; so that not only is there absorption of heat in the cell itself, due to the character of the chemical changes occurring as the current passes, but, further, any work done outside the cell must be at the expense of the sensible heat of the cell itself.

5. *On the Sensitiveness to Light of Selenium and Sulphur Cells.*[1] *By* SHELFORD BIDWELL, *M.A., LL.B.*

The fact first announced by Mr. Willoughby Smith in 1873 that the electrical resistance of crystalline selenium is temporarily diminished by the action of light has been fully confirmed by subsequent experimenters. Of the many investigations which have been undertaken in reference to this subject, by far the most valuable and exhaustive are those of Professor Adams and Mr. R. E. Day, an account of which was published in the 'Philosophical Transactions' for 1877. These gentlemen arrived at the conclusion that the diminution in the resistance of selenium might be accounted for by the fact that light promotes crystallisation, for in changing to the crystalline state selenium becomes a better conductor of electricity. They also state their belief that selenium conducts electrolytically; but it may be inferred from the paper—and was indeed explained by Professor Adams himself at the meeting of the Physical Society on June 13 last—that the authors did not suppose that actual electrolysis occurred, but rather that the molecular structure or crystalline condition of the substance was altered or modified by the action of a current of electricity in such a manner as to produce effects analogous to those which would have occurred if the selenium were an electrolyte, and actually decomposed by the current.

A new form of selenium cell has recently been described by Mr. C. E. Fritts, of New York. A thin film of selenium is spread upon a plate of some metal, such as brass or copper, with which it will form a chemical combination. The selenium is melted and crystallised under pressure, and, when cold, its surface is covered with a film of gold-leaf sufficiently thin to transmit light. The metal plate and the gold-leaf form the two electrodes of the cell, the resistance of which is varied by the action of the light which passes through the gold-leaf.

Upon reading this description, it occurred to the author that the conduction of selenium, when prepared in the form of cells, might be in reality, and not merely in appearance, electrolytic. Selenium will, he believes, combine more or less readily with all metals, the combination being assisted by heat. And in the preparation of selenium cells it has been the usual, if not the universal custom, to submit the selenium to prolonged heating while in contact with metallic electrodes. This operation is generally called 'annealing,' and the undoubted fact that it diminishes the resistance of the selenium and increases its sensitiveness to light has been explained by supposing that the process is favourable to perfect crystallisation. The author suggests as an alternative explanation that the prolonged heating, by promoting the combination of the selenium with the metal of the electrodes, results in the formation of a selenide which completely surrounds the electrodes, and is perhaps diffused to some extent throughout the selenium when it is in a liquid condition; and that the apparently improved conductivity of the selenium, together with the electrolytic phenomena which it exhibits are to be accounted for by the existence of this selenide. It was found that while the specific resistance of the selenium contained in a well-annealed cell having copper electrodes was ·9 megohm, that of a similar piece of selenium annealed in a glass mould without contact with any metal was as much as 2,500 megohms. This enormous difference is to be attributed to the presence of selenide of copper in the selenium of the cell.

The above hypothesis has not been submitted to the test of direct experiment, but certain indirect evidence in support of it has been forthcoming. Selenium is an element which, in its properties, closely resembles sulphur, and many unsuccessful attempts have been made to develop in sulphur that peculiar sensitiveness to light which is such a remarkable characteristic of selenium. It occurred to the author that if this property of selenium were really due to the accidental existence of metallic selenides, then the admixture with sulphur of metallic sulphides might be expected to lead to similar effects. Several cells were therefore constructed, in which selenium was replaced by sulphur containing a proportion of silver sulphide,

[1] Published *in extenso* in the *Electrician*, Sept. 18, 1885, and in the *Chemical News*. See also *Phil. Mag.*, Aug. 1885.

the electrodes being formed of silver wire, and they all turned out to be more or less sensitive to light, and to exhibit other properties of annealed selenium.

When, as in the case of these cells, a current of electricity passes between silver electrodes through a mass of sulphide of silver, silver will be deposited upon the cathode, and sulphur upon the anode. Now sulphur has an enormously high resistance, and the existence of a mere film of free sulphur upon one of the electrodes would be sufficient to stop the current altogether. The current is not, in fact, stopped, because the deposited sulphur combines with the silver of the anode, merely adding a new layer to the electrolyte. Thus the metal of the anode gradually combines with the sulphur of the electrolyte, and the conductivity of the arrangement will depend, to a great extent, upon the facility with which this combination is effected. It might therefore be expected that the resistance of a sulphur cell with silver electrodes would be diminished by any influence which assisted the combination of silver with sulphur. Experiment shows that such an influence is exerted by light.

But it is not perhaps necessary to assume that the effective action of light is confined entirely to the electrode. It seems reasonable to suppose that any circumstances which are favourable to the union of two substances when they have a tendency to unite would also be favourable to their separation when from any cause they have a tendency to separate. If, then, as is commonly supposed, electrolysis involves a series of decompositions and recompositions, both these processes would be assisted by the same agency which, under ordinary conditions, favours the union of the constituents of the electrolyte. The electrolysis of silver sulphide may therefore be assisted by light, and its electrolytic resistance at the same time diminished.

Although results similar to those above described have not yet been obtained when other metals than silver have been used in conjunction with sulphur, the author believes it probable that the action of light upon the resistance of selenium in conjunction with any metal whatever with which it forms a sensitive combination is of a nature analogous to that which occurs in the case of sulphur and silver.

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6. *On the Generation of a Voltaic Current by a Sulphur Cell with a Solid Electrolyte.*[1] *By* SHELFORD BIDWELL, *M.A., LL.B.*

While observing the secondary or polarisation currents, which are generated by sulphur cells (as by those made with selenium), after being disconnected from a battery, certain effects were noticed which seemed to indicate that when the electrodes consisted of two different metals, a sulphur cell might be capable of originating an independent or primary current. Experiments were therefore made with the object of investigating this point, and some of the results obtained are here given, though without any attempt to explain them, or to connect them together by a complete theory. They appear, however, to possess sufficient interest to render them worthy of record from the fact that no voltaic arrangement with a solid electrolyte has hitherto been constructed which—at least at ordinary temperatures—was capable of producing the smallest effect upon the most delicate galvanometer.

A plate of copper about one inch square was heated, and upon it was spread a mixture consisting of five parts of sulphur and one part of sulphide of copper. A plate of silver previously heated was then laid upon the melted mixture, and the two plates were squeezed together, thus forming a sandwich-like cell. When this cell, after cooling, was connected with a reflecting galvanometer, the spot of light was violently deflected off the scale. From very careful measurements it appeared that the E.M.F. of the cell was ·0712 volt, and its internal resistance 6537 ohms. The direction of the current was from the silver through the electrolyte to the copper, and there could be no doubt that it was of a voltaic nature. After the cell had been in existence for about three months, its E.M.F. had not materially fallen off.

[1] Published *in extenso* in the *Electrician*, September 18, 1885, and in the *Chemical News*. See also *Phil. Mag.* October, 1885.

The current was small owing to the great internal resistance of the cell, and attempts were made to reduce this resistance by diminishing the proportion of free sulphur. But it was found that when the resistance was reduced in this manner the E.M.F. was also reduced, and when there was nothing but simple copper sulphide between the plates, there was no sensible E.M.F. whatever.

Another cell was made in which powdered silver sulphide without any free sulphur was compressed between plates of silver and copper. This arrangement generated a current, the direction of which was opposite to that produced by the cells above described, but the E.M.F. rapidly fell off, and in three or four days had almost completely disappeared.

When a similar cell was constructed in which the silver sulphide was mixed with sublimed sulphur and placed in the form of a powder between the plates, the direction of the current was, as with simple silver sulphide, from copper to silver. But if the mixture was first fused and the plates between which it was compressed heated, the current generated by the cell when cold was in the reverse direction. Sulphide of copper was undoubtedly formed in the process of construction.

Consideration of these results led the author to believe that the sole function of the free sulphur in the copper sulphide cell was to form a film of silver sulphide by direct combination with the silver plate. A cell was therefore made as follows:—A layer of copper sulphide was spread upon a plate of copper, a polished steel plate was laid upon the sulphide, and the whole was strongly compressed in a vice. The steel plate was then removed and a thin layer of silver sulphide was spread upon the smooth surface of the copper sulphide. The cell was completed by pressing a silver plate upon the silver sulphide. This was found upon trial to give a current which, with an external circuit of low resistance, was many times stronger than that generated by any of the cells previously made. Its action was probably analogous to that of a Daniell's cell consisting of plates of zinc and copper in solutions of zinc sulphate and copper sulphate. The quantity of the copper sulphide would be gradually diminished, copper being deposited on the copper plate, while the quantity of the silver sulphide would continually increase with consumption of the silver.

A very curious experiment observed in the course of the experiments was the following:—If a battery current was passed for a short time through a cell containing two silver electrodes embedded in a mixture of sulphur and copper sulphide, the cell after being disconnected from the battery generated a current of very short duration (not impossibly due to thermo-electric action) in the direction opposite to that of the battery current; and this current, which rarely lasted for more than two or three minutes, was followed by another which was in the same direction as the battery current, and was generally maintained for several hours.

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7. *A Theory of the Connection between the Crystal Form and the Atom Composition of Chemical Compounds.*[1] *By* WILLIAM BARLOW.

The author bases a theory of the origin of the symmetry of crystals upon the hypothesis that the different kinds of chemical atoms of a crystallising body so far preserve their individuality in the combined state as to personally attract or repel one another differently.

His theory is that liquid matter in the act of crystallising, just before solidification takes place, has the chemical atoms of different kinds which compose it symmetrically arranged in space with respect to one another, and that this symmetrical disposition of the atoms is the direct consequence of different degrees of attraction and repulsion exercised by the different kinds of atoms during fluctuations in the distances between them which are caused by waves of alternate condensation and rarefaction traversing the mass. He supposes that crystallisation occurs only in those cases in which the different kinds of atoms are present in such proportions as will admit of the necessary symmetrical arrangement.

[1] Published *in extenso* in the *Chemical News*, January 1 and 8, 1886.

After having argued the probability of the theory from first principles, the author traces several systems of symmetrical arrangement for various different atom proportions, and points out that these systems are in harmony with the known crystal forms. The pair of systems which he derives for the atom proportions of quartz have spiral dispositions of the same kind of atom, right-handed in one, left-handed in the other, such as may account for the production of right-handed or left-handed rotation of a polarised ray by crystals of the substance.

The cause of dimorphism is suggested, and symmetrical systems of arrangement of the atoms indicated for the dimorphic forms calc-spar and aragonite.

The different expansion in different directions of crystals not of the regular system is explained.

The phenomenon of twin crystals is shown to be in harmony with the theory.

A general theory of isomorphism is submitted; the case of isomorphism of ammonic sulphate and potassic sulphate being specially referred to.

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8. *On the use of Sodium or other soluble Aluminates for softening and purifying hard and impure water, and deodorising and precipitating sewage, waste water from factories, &c. By* F. MAXWELL LYTE, *F.C.S.*

Roscoe gives the formula for sodium aluminate as $Na_2Al_2O_4$, and this nearly agrees with the composition of the soluble portion of the crude salt. But, owing to its tendency to lose alumina on keeping in solution, even in closed bottles, and to the invariable presence of soluble silicates, the dissolved salt has practically rather the formula $Na_6Al_4O_9$.

Sodium aluminate is decomposed by all soluble acids and acid salts, and even by many strictly so-called neutral salts, among them being the sulphates, chlorides, and nitrates of the earthy and heavy metals. In this latter case a corresponding portion of earthy or metallic hydroxide is liberated, or rather the earthy or metallic oxide remains so loosely combined with the precipitated alumina that it is practically free even to the point of being decomposed by carbonic acid, with the formation of a carbonate of the base it contains, thus destroying a like amount of temporary hardness if present, just as the aluminate itself has already destroyed a certain number of degrees of permanent hardness. Thus (if we adopt Roscoe's formula)—

$$Na_2Al_2O_4 + CaSO_4 + CO_2 + 3H_2O = Na_2SO_4 + 1CaCO_3 + Al_2(HO)_6.$$

The aluminium hydroxide takes down several times its own weight of organic matter, and thus may be produced—

(A) Precipitation of any organic impurity.
(B) Destruction of the permanent hardness.
(C) Destruction of the whole or part of the temporary hardness.

If the permanent and temporary hardness balance one another—*i.e.*, are equal in amount—an addition of aluminate only sufficient for the permanent hardness will gradually destroy both it and a like number of degrees of temporary hardness.

But if, as however is not often the case, the permanent hardness so far exceeds the temporary that there is not sufficient carbonic acid in solution to throw down as carbonate all the lime or other base producing the permanent hardness, a little sodium bicarbonate may be added, or, in order to keep down to a minimum the soluble sodic salts, a little phosphoric acid.

If the temporary hardness be in excess, it may be destroyed by Clark's method, or a little more aluminate may be added.

The time required for the precipitation of the aluminium salts and formation of the calcium and other carbonates, varies with different waters from a few minutes to a few hours, so that where time is an object it may be advisable to use some kind of rough filter. Indeed water so softened and purified passes easily and filters perfectly. Where water is contaminated with organic substances, but contains no appreciable hardness, or where it is desired to retain its hardness so as not to lose

its freshness, the sodium aluminate may be precipitated with aluminium sulphate, when the following reaction takes place:—

$$3Na_2Al_2O_4 + Al_2(SO_4)_3 18H_2O = \\ 3Na_2SO_4 + 4Al_2(HO)_6 + 6H_2O.$$

Indeed as the decomposition of the insoluble aluminate formed only takes place slowly, it is best to use this method in addition, even when adding the aluminate alone for softening, in all cases where much organic matter is present which it is desired to get rid of, and thus it is very applicable to the purification of sewage, waste waters from factories, &c. Its advantages consist—

(1) In its economy over every other known method of precipitation by aluminium hydroxide.

(2) The comparatively harmless nature and small proportion of the salt left in solution.

The usual way of obtaining the hydroxide is by aluminium sulphate and lime or chalk. But the sulphate (even the pure crystallised salt) contains only 15·44 per cent. of alumina (the commercial salt about 2 per cent. less), while sodium aluminate contains 52½ to 62½ per cent. and even the crude salt of commerce now obtainable abroad 33 per cent., so that a very much smaller quantity of the latter will suffice to produce a given quantity of hydroxide. Again, by using the sulphate with any salt other than the aluminate, the quantity of matter left in solution would be greatly increased, while in the case of lime or chalk with sulphate the effluent would possess that objectionable quality, 'permanent hardness.'

As to the question of cost, sodium aluminate has never been manufactured in England on a large scale, so that its price at present is abnormally high, though there is reason to believe that ere long it will fall considerably. As it is, where water possesses 20 degrees of hardness—*i.e.*, 10 permanent and 10 temporary—it can be freed from both these, as well as from any organic matter, for about 2*d.* per 1,000 gallons. Practically, and using the crude salt, the expenditure in the above case would be only just over 1 grain per gallon and per degree of hardness. The simple purification of water or sewage would be considerably less.

In experimenting practically with the above process for purifying sewage and waste waters it must be borne in mind, first, that great care must be taken to obtain a proper aluminate; and, secondly, that the salt should *not* be previously dissolved, but added, finely powdered, to the liquid it is desired to purify.

TUESDAY, SEPTEMBER 15.

The following Reports and Papers were read:—

1. *Report on Vapour Pressures and Refractive Indices of Salt Solutions.* See Reports, p. 284.

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2. *Report on certain Physical Constants of Solution.*—See Reports, p. 261.

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3. *On Solutions of Ozone and the Chemical Actions of Liquid Oxygen. By* Professor DEWAR, *F.R.S.*

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4. *On Physical Molecular Equivalents.*[1] *By* Professor GUTHRIE, *F.R.S.*

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[1] Published in the *Chemical News*, 1885.

5. *The Size of Molecules.* *By* Professor A. W. REINOLD, *M.A.*, *F.R.S.*

The four lines of argument by which Sir W. Thomson has been led to form an estimate of the size of a molecule are, briefly, as follows:—

1. *Argument from the Refractive Dispersion of Light.*—If transparent substances like water, glass, &c., were infinitely homogeneous, the velocity of propagation of light through them would be independent of the period of vibration or wave-length. The fact that the velocity of propagation does depend on the period is irrefragable proof that such transparent substances are not infinitely homogeneous—*i.e.*, the coarse-grainedness of such substance is comparable with the wave-length of light. Cauchy was the first to arrive at this conclusion, but his theory leads to results altogether untenable. The same general principle is, however, applicable, and by making certain assumptions as to the connection between the ether and the heavier particles of matter, results may be obtained in agreement with those derived from other considerations.

2. *Argument from the Phenomena of Contact Electricity.*—If a plate of zinc and a plate of copper be brought into contact with each other, they become oppositely electrified and attract each other. Let the plates be each a square centimetre in area, and, after being made to touch, let them be brought to a distance of 10^{-8} centimetres from each other. The work done by electrical attraction while the plates are allowed to approach each other is about $2 \times 10^{6} \times 10^{-8} = 2 \times 10^{-2}$ centimetre-grammes. If now a third plate, of copper, be similarly placed upon the zinc platean, equal additional amount of work will be done by electrical attraction, and by making a pile of plates, alternately of zinc and copper, an amount of work will be done by electrical attraction proportional to the number of plates employed. Suppose a pile so constructed of 100 millions and one plates, 50 millions and one of zinc, and 50 millions of copper, each plate being the hundred millionth of a centimetre thick, and the distance between the plates the 100 millionth of a centimetre. The volume of the metal will be a cubic centimetre, and its mass 8 grammes. The work done by electrical attraction will be 2×10^{6} centimetre-grammes, or, $\frac{1}{4} \times 10^{6}$ centimetre-gramme per gramme of metal. To raise the temperature of 1 gramme of zinc or copper, the heat required is equivalent to 4030 centimetre-grammes. Hence the work done by electrical attraction would, in the form of heat, raise the temperature of the mass by $\frac{1}{4} \times 10^{6} \times \frac{1}{4030} = \frac{10^{6}}{16{,}120} = 62°$ C, which is not improbable according to our present knowledge of the heat of combination of zinc and copper. By supposing the plates and intervening spaces to be made yet four times thinner, it is shown, in a similar manner, that the temperature attained would be 990°. A result requiring more heat than is produced by the chemical union of copper and zinc. Hence plates of zinc and copper $\frac{1}{300{,}000{,}000}$ centimetres thick, placed close together alternately, form a near approximation to a chemical combination, if indeed such plates could be made without splitting atoms. This argument, therefore, gives $\frac{1}{30}$ M. (M = millionth of a millimetre) as the diameter of a zinc or copper particle.

3. *Argument from Liquid films.*—The surface tension of water is 81 dynes per centimetre, corresponding to about 8 milligrammes per millimetre. Therefore in the case of a water film with two faces the contractile force is 16 milligrammes per millimetre. Hence the work done in stretching a film of water, measured in milligramme-millimetres, is 16 times the number of square millimetres by which its area is increased. But the film is cooled in being stretched, and Sir William Thomson has shown that half as much energy must be supplied to the film in the form of heat to maintain its temperature constant. Hence the intrinsic energy of a mass of water in the shape of a film kept at a constant temperature is increased 24 milligramme-millimetres for every square millimetre added to its surface. Starting with a film of a thickness of one millimetre, and supposing it to be stretched until its area is increased 10,000 fold, the heat equivalent to the work done in stretching it, supposing the temperature to remain constant, is calculated. It is thus shown that work spent in stretching this film until its thickness is $\frac{1}{10{,}000{,}000}$ millimetre, would, in the form of of heat, cause a rise in temperature sufficient to vaporise the

film. This amount of work is far more than can be admitted, and the conclusion is inevitable that a water film falls off greatly in its contractile force before it is reduced to a thickness of $\frac{1}{10,000,000}$ millimetre. Such a falling off in the contractile force would indicate that there are not several molecules in this thickness of water.

4. *Argument from the Kinetic Theory of Gases.*—Supposing the molecules of a gas to be hard elastic globes all of one size, influencing one another by actual contact only, each molecule will move along in a zigzag path consisting of rectilinear portions, with abrupt changes of direction. Clausius has shown the average length of a free path of a particle, from collision to collision, to bear to the diameter of each globe, the ratio of the whole space in which the globes move to $6\sqrt{2}$ times the sum of the volumes of the globes. Or if λ be the average length of free path, σ = diameter of a globe, v = volume of the globes in 1 c.c. of gas, then $\sigma = 6\sqrt{2}\, v\, \lambda$. Since it is inadmissible to suppose that, in the liquefaction of any of the ordinary gases, they could be made 40,000 times denser than at ordinary temperature and pressure, without reducing the whole volume to less than that of the sum of the globes, the free path must not be more than 5,000 times the diameter of the gaseous molecule. The average length free path of each molecule from collision to collision in the case of oxygen, nitrogen, or air, has been shown to be $\frac{1}{100,000}$ of a centimetre. The diameter of the gaseous molecule, therefore, cannot be less than $\frac{1}{500,000,000}$ centimetre, *i.e.*, 2×10^{-9} or $\frac{1}{50}$ M (millionth of a millimetre). Nor can the number of molecules in a c.c. of gas be greater than 6×10^{21}. Since the densities of known liquids and solids are from 500 to 16,000 times that of air, at ordinary pressure and temperature, the number of molecules in a c.c. may be from 3×10^{24} to 10^{26}. Assuming a cubic arrangement of molecules, the distance from centre to nearest centre in solids and liquids may be estimated at from $\frac{1}{140,000,000}$ to $\frac{1}{460,000,000}$ millimetres.

These four lines of argument show that in liquids and transparent solids the mean distance between the centres of contiguous molecules is something between $\frac{1}{10}$th and $\frac{1}{200}$th of a millionth of a millimetre.

Quite recently Professor F. Exner has shown that v in the formula $\sigma = 6\sqrt{2}\, v\, \lambda$, mentioned above, may be calculated in another way. Starting from Faraday's assumption that a dielectric consists of particles of conducting substance distributed throughout its mass and separated from each other by absolutely non-conducting (void) spaces, and supposing v = the sum of the conducting particles in 1 c.c. of dielectric, Clausius has shown, supposing the particles to be spheres, the following simple relation to hold between v and the specific inductive capacity of the dielectric viz., $v = \frac{K-1}{K+2}$. Further, according to Maxwell's theory, $K = n^2$, where n = the refractive index of the substance. Hence in the case of gases the formula $v = \frac{K-1}{K+2} = \frac{n^2-1}{n^2+2}$ may be applied. The values obtained by this method for the diameter of a molecule are smaller than those obtained by the other methods, but of the same order of magnitude.

The author goes on to give a brief account of the experiments on soap films, conducted by himself conjointly with Professor Rücker ('Nature,' vol. xxxii., p. 210), the results of which, even when the highly complex character of the liquid employed is considered, are not out of accord with the estimate of Sir W. Thomson as to the size of molecules, although the upper limit given in 1873 by the latter (viz., $\frac{1}{5}$ M), is probably too high.

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6. *An approximate determination of the Absolute Amounts of the Weights of the Chemical Atoms.* *By* G. Johnstone Stoney, *D.Sc., F.R.S.*

Several inquiries (see Professor Loschmidt, 'Zur Grösse der Luftmolecule,' *Academy of Vienna,* Oct. 1865; G. Johnstone Stoney on 'The Internal Motions of Gases,' *Phil. Mag.* August, 1868; and Sir William Thomson on 'The Size of

Atoms,' *Nature*, March 31, 1870) have led up to the conclusion that the number of molecules in each cubic millimetre of a gas at atmospheric temperatures and pressures is somewhere about a unit-eighteen (10^{18}). Hence, the number of molecules in a litre will be about a unit-twenty-four (10^{24}). Now, a litre of hydrogen at atmospheric pressures and temperatures weighs, roughly speaking, a decigramme There is no advantage in taking account of the ratio of 1·2 decigramme to 1 decigramme. Hence, the mass of a molecule of hydrogen, or weight, as it is called by chemists, is a quantity of the same order as a decigramme divided by 10^{24}—*i.e.* a twenty-fourth decigramme, which is the same as the twenty-fifth grammet. (The grammets are the decimal subdivisions of the gramme, of which the first is the decigramme, the second the centigramme, and so on.) Hence, the mass of the chemical atom of hydrogen may be taken to be about half the twenty-fifth of the grammets. There is no use in retaining the co-efficient 'half' in an estimate in which we cannot be certain to a unit that we have assigned the right power of 10, and we may, therefore, for the sake of simplicity, take the twenty-fifth grammet itself as being such an approach as we can attempt to the value of the mass of the chemical atom of hydrogen.

Having obtained the mass of one atom, that of hydrogen, the masses of the atoms of the other simple substances bear the ratios to this that are assigned to them in the table of atomic weights, and the masses of molecules of compounds can be derived directly from these in accordance with their formulæ, so that all are approximately known.

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7. *On Macromolecules (Molecules of Matter in the Crystalline State as distinct from the Chemical Molecule), and determinations of some of them.* *By* G. JOHNSTONE STONEY, *D.Sc*, *F.R.S.*

The molecule of a crystal is usually found, in the few cases in which an investigation is possible, to include several chemical molecules. On this account the author has suggested that they be called macromolecules, as in reference to them the chemical molecule is a sub-molecule.

In a communication made two years ago to the British Association, it was shown that although each chemical atom of a solid may be in a state of internal motion, this motion must be such that a point can be assigned within each atom (and which is determined by an integration similar to that by which centres of gravity are determined) which point is a fixed point in solids, and a travelling point if the atom be an atom of a liquid or gas. This for convenience may be called the centre of the atom. In a crystal, these centres are all in fixed positions and at definite distances asunder, so that a diagram may be conceived consisting of these points, with lines connecting them wherever the corresponding atoms are chemically in combination. The chemical formula limits geometrically the number of positions relatively to one another in which these points can stand within one chemical molecule.

The only hypothesis that needs to be made is at this stage and the next, at both of which it is assumed that the bonds or connections between the chemical molecules of a solid are identical with the bonds found by Chemistry between the atoms of chemical molecules, being some not used in forming that particular sub-molecule.

By this hypothesis the diagram can be extended to a group of chemical molecules, and, as before, there is geometrically only a limited number of such diagrams possible.

Finally, these groups or macromolecules are again connected together by chemical bonds not yet employed, and these final connections must be such that the resulting form &c. are identical with the observed crystalline form with all its faces and with its cleavage planes, &c. All these when known furnish conditions that limit the number of possible arrangements at the preceding stages, and if the number of such conditions be sufficient, or where the crystalline form is sufficiently complicated, and especially where hemihedral faces occur, they give an indication as to which of the possible arrangements at the preceding stages is the real one. In a few cases it has been possible in this way to make out with considerable

probability what the arrangement at each step is, and thus to trace a connection between the chemical constitution and the crystalline form, &c.

Thus in iron pyrites, FeS_2, the hemihedral form with parallel faces which is characteristic of this mineral, and which is from it called the pyritohedron, can be traced on from the chemical molecule FeS_2 through a macromolecule which includes six of these as sub-molecules, and which is connected with the other similar macromolecules in a regular way.

So, again, the general form and tetrahedral hemihedralism which are found in boracite can be traced from its formula,

$$3MgO, 4B_2O_3,$$

through macromolecules each of which contains four of these chemical molecules.

And, again, the two kinds of hemihedralism, the right-handed and the left-handed, which present themselves in different specimens of quartz, can be traced from the chemical molecule SiO_2 through a macromolecule which contains six of these connected in one or other of two possible ways, and thence on to the two crystalline forms of the perfect crystal that present themselves.

There is therefore reason to believe that in each of these crystals the macromolecule or crystalline molecule consists of several chemical molecules, and must be carefully distinguished from the latter, containing in iron pyrites six, in boracite four, and in quartz six, chemical molecules.

8. *On the Dilatancy of Media composed of Rigid Particles in Contact.* *By* Professor Osborne Reynolds, *F.R.S.*—See Section A, p. 896.

9. *On the Evidence deducible from the Study of Salts.* *By* Spencer U. Pickering.

In this paper the author dealt with the evidence as to the molecular weights of salts, derived from a study of the composition (1) of hydrated salts; (2) of basic salts; (3) of double salts. He also criticised the evidence deducible from experiments on hydration, dehydration, and the vapour tension of hydrated salts, and finally examined the conclusions drawn from the calorimetric investigations of such compounds. The conclusions arrived at by the author are, that, although in a few isolated cases the molecular weight obtained would appear to be greater than the analytical results necessitate, still in a vast majority of cases there are no grounds for multiplying these weights, and, indeed, there is a considerable mass of evidence in favour of adhering to the simplest possible formulæ. Such a conclusion may, at first sight, appear opposed to conclusions drawn from other sources. On the one hand the author considers it undeniable that if we succeed in determining the number of replaceable portions of the elements in any compound, we determine *ex hypothesi* the number of atoms in the molecule—that is the molecular weight—and although the data at our disposal at present are of the most meagre description, they nevertheless seem to point incontestibly to the simplicity of these molecules. On the other hand, considerations based on the crystalline form and other physical properties of bodies force on us the conclusion that liquid and solid molecules are in all probability of a very complicated nature, certainly more complicated than gaseous molecules. Both these conclusions the author considers to be reconcilable with one another, and contends that because the smallest particle of a substance which enters into a chemical reaction may be simple, there can be no reason why many of these particles may not agglomerate and act in unison as regards certain physical forces. That this agglomerate does not act as a unit towards chemical forces would simply imply that the force which unites the individuals constituting it is not chemical force, or is chemical force of such a weak nature that, in presence of the strong chemical agents we make use of, it is inappreciable. The molecule of a chemist is not necessarily identical with the molecule of a physicist.

10. *On the Molecular Weights of Solids and Salts in Solution.* *By* Professor W. A. Tilden, *D.Sc.*, *F.R.S.*

It seems to be generally agreed that bodies in the *solid* state consist of units or molecules which are very complicated and made up a of considerable number of such smaller aggregates as compose the molecules of gases. Accepting the conclusion, the author is disposed to go further, and to say that in any given case there appears to be no reason for limiting the number of small molecules which may thus be bound together to form the physical unit of a solid. The law of Dulong and Petit, and Neumann's law, according to which every elemental atom, whether free or in combination, has the same, or nearly the same, specific heat, point to a conclusion of this kind. The law of Dulong and Petit states that, approximately at least, the specific heat in the solid element is inversely as the atomic weight, or as *n times the atomic weight*. This seems to indicate that, since *n* may be made as large as you please, there is in solids of this kind, and in salts, &c., no difference between *molecule* and *mass*, and that the physical unit is the atom. The same kind of argument may be deduced from the facts known concerning the specific volumes and refraction equivalents.

Solid bodies according to this view are composed of atoms which are only distributed into molecules capable of taking up an independent state of existence when the body becomes fluid.

Such a hypothesis involves or implies another, viz., that chemical combination between atoms and the combination of molecules which ensues when a gas or a liquid returns to the state of solid are phenomena of the same nature. This agrees with the commonly recognised resemblance between the process of dissociation and the processes of fusion and of evaporation. In both the change is gradual and is dependent upon temperature, and both are directly measurable in terms of heat or some other form of energy. Another consequence of this view is that we must confine the idea of *limited* valency to gaseous substances. From the well known numerous double salts, and especially such compounds as the periodides of the organic bases, it appears, in the solid state, the elements and especially the non-metallic elemental radicles, are capable of developing an indefinitely large capacity for combination. None of these so-called molecular compounds exist in the gaseous state.

With regard to solutions there are many facts which indicate that the molecules of dissolved substances are smaller than those of solids. Thus it appears that the alums, the numerous double iodides and chlorides, and such compounds as racemic acid, exist only in the solid state. When they pass into solution they are resolved into their proximate constituents. To determine whether common salt in solution is NaCl or *n* times NaCl seems almost an insoluble problem. The question of water of crystallisation is related to this subject, and here we have some evidence, though conflicting. On the one hand we have the evidence of such experiments as those of Dr. Nicol on the molecular volumes of salts in solution, from which it appears that the water of crystallisation of a salt dissolved in water is not distinguishable from the rest of the water with which the salt is mixed. But if this means that when a salt such as copper sulphate, for example, is dissolved in water, the water combined in the crystal separates from it, leaving the salt molecule to wander free, the author can not assent to this view. By this hypothesis we can explain neither the colours of such solutions, nor the large evolution of heat which ensues on the introduction of such a salt in the anhydrous state into water.

The composition of the salt molecule in solution appears to be dependent chiefly upon temperature. If we dissolve in water a salt like common salt, which habitually crystallises without water of crystallisation, the salt molecule in solution at ordinary temperatures does not include the elements of water, in other words the salt dissolves in the anhydrous state. But if we take a salt such as sodium sulphate, the dissolved molecule retains the same amount of water as the crystals formed at the same temperature, whilst if the temperature is raised these molecules are gradually broken down until at a certain temperature all the salt molecules

present give up their water and become anhydrous. The author has now satisfied himself by experiment that this decomposition or dissociation is progressive and does not take place *per saltum*. Taking sulphate of sodium, which has its point of maximum solubility at 34° and above that point deposits the anhydrous salt, he has made determinations of the rate of cooling of a strong solution and finds the time-temperature curve to be parallel with that of water done under the same conditions. Calorimetric determinations of the heat of solution of the anhydrous salt at successive temperatures lead to the same conclusion.

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11. *On the Molecular Constitution of a Solution of Cobaltous Chloride.* *By* Professor W. J. Russell, *Ph.D., F.R.S.*

A thin layer of cobaltous chloride gives an absorption spectrum consisting of two broad ill-defined bands. If the chloride be fused with potassium, sodium, or calcium chloride, the spectrum of these mixtures, both in the solid and fused state, is different from that of cobaltous chloride, alone and consists essentially of four bands, two of which are marked and characteristic. This same spectrum is obtained with solutions of cobaltous chloride in absolute alcohol, in amyl alcohol, in hydrochloric acid, and in glacial acetic acid. This spectrum would, therefore, appear to be that of cobaltous chloride in an altered molecular state. The spectrum of an aqueous solution is again different, and consists of one broad band nearer to the blue end than the other bands, but the addition of cobaltous chloride to such a solution, or of such bodies as possess an affinity for water, causes a reversion of the spectrum to that of the anhydrous cobaltous chloride. Heat also produces the same effect, and it would appear from these results that the anhydrous chloride can exist in aqueous solutions. The changes in the character of a spectrum of an aqueous solution produced by heat may be explained as arising from a dissociation of some of the hydrates existing in the solution, and the production of anhydrous cobaltous chloride. Further, the fact that those solutions containing the anhydrous salt more readily transmit the blue rays and absorb the red rays, whilst those containing hydrates in solution more readily transmit the red rays, would indicate that the molecule of the hydrate is smaller than that of the anhydrous salt. The action of water on the anhydrous salt, therefore, is not to form an additive compound, but to split the molecule of the anhydrous salt and form one in which water replaces cobaltous chloride.

WEDNESDAY, SEPTEMBER 16.

The following Papers were read:—

1. *An Electro-centrifugal Machine for Laboratory use.*[1] *By* Alexander Watt, *F.I.C., F.C.S.*

This instrument, although in itself possessing no scientific interest, has been found so useful in the laboratory as to justify the hope that a description of it and a demonstration of its use may prove of interest.

The late Dr. Mohr, of Bonn, in his 'Titrirmethode' advocated the use of a centrifugal machine for the rapid drying of crystalline precipitates, for use in volumetric analysis, and although they are admirably adapted for such purposes, centrifugal machines are seldom seen in our chemical laboratories. It is possible that the neglect of this valuable addition to our laboratory apparatus is owing to the inconvenience involved in driving the machine at a high speed by means of the ordinary pulleys or other speed-increasing gear, especially when the rotation has to be kept up for a considerable length of time.

[1] Printed in full in the *Chem. News*, vol. 52, p. 232.

It therefore occurred to me, that by directly attaching an electro-motor to the revolving drum or basket (or table as in Mohr's instrument), the inconvenience attending the driving might be got over, and at the same time a combination of great efficiency would result, as the electro-motor like the centrifugal machine is most efficient when driven at a high speed.

The apparatus consists essentially of a basket or drum of perforated copper (it might be of iron, or other suitable metal, or of ebonite) slipped on to a cone attached to the spindle of a small electro-motor, and is held in position by means of a nut. The surrounding casing serves to catch the liquid driven out of the substance being dried. The electro-motor consists of a Siemens H armature, which revolves between the poles of an electro-magnet of soft iron. The centrifugal machine, as is well known, has many industrial applications. It is used in laundries and in the textile manufactures for drying wool and cloth, in dyeworks for drying feathers, and in the manufacture and refining of sugar, for the separation of the sugar crystals from the syrup, but it is only quite recently that chemical manufacturers have awakened to its value.

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2. *Barium Sulphate as a Cementing Material in Sandstone.* *By* Professor Frank Clowes, *D.Sc.*—See Section C, p. 1038.

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3. *An Apparatus for determining the Viscosity of Oils.* *By* A. H. Allen, *F.C.S.*

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4. *The Action of Nitrous Gases upon Amyl Alcohol.* *By* J. Williams, *F.C.S., F.I.C., and* Myles H. Smith, *F.C.S.*

Having had occasion lately in the manufacture of amyl nitrite, to determine for commercial and manufacturing purposes the best mode of producing the largest possible result from a given amount of materials, the following results were obtained.

We should mention that in all the trials the same sample of amyl alcohol was employed. This had been well purified by washing, fractional distillation, and several distillations in the vapour of steam; it was therefore practically nearly pure, but may still have contained traces of ethylic and butylic alcohols, and perhaps other bodies.

The nitrous gases were produced by the action of nitric acid of various strengths upon arsenious acid. With the very strong acids it was necessary that the arsenious acid should be in lump to moderate the action.

It was found that the gas produced by nitric acid of sp. gr. 1500 was nearly entirely absorbed by the amyl alcohol, which when completely nitrified changed in colour from a bright yellow to a greenish-brown. The product, washed and distilled, gave only from 42 to 48 parts distilling under 100° C., about 85 parts under 120°, and remainder boiling at a considerably higher point. This result was very unsatisfactory, and proved that the gas produced by acid of this strength was nearly pure nitrogen tetroxide, which in contact with the amyl alcohol was split up into nitrous acid (producing less than one-half nitrite amyl) and nitric acid, producing higher products of oxidation.

Nitric acid of 1420 was then tried. Much of the gas was absorbed, but a considerable quantity of unabsorbable gas was produced, and the product yielded about 65 to 70 parts of a distillate coming over at 100° or a little above. This result, although better, was not at all satisfactory.

Nitric acid of 1350 gave a gas which contained a still larger proportion of unabsorbable gas, but ultimately yielded a product which gave on one occasion as much as 90 per cent. of distillate under 100°, and 95 under 105°.

When nitric acid of sp. gr. 1300 was employed, most of the gas obtained was unabsorbable, but a small percentage of absorbable gas was obtained, which

after some time was sufficient to complete the reaction. The product, washed and distilled, gave a result yielding as much as 95 per cent. of distillate under 100°.

It appeared evident from the experiments that acid of a medium strength, say 1350, was better adapted for our purpose than either very strong or very weak acid. That, in fact, the very strong acid produced little else than nitrogen tetroxide, and the very weak acid mainly nitric oxide. We determined to try a mixture of these two gases.

The nitrogen tetroxide was produced by acting upon arsenious acid by nitric acid of sp. gr. 1500, or, in a later experiment, by acid of 1520. The nitric oxide was made by adding nitric acid to nitrite of sodium, or, in the latter experiments, by acting upon copper turnings by nitric acid. The gases were allowed to mix in a glass vessel, care being taken to keep the nitric oxide in considerable excess. Under these circumstances the mixed gases were freely absorbed, some unabsorbable gas being of course given off. And the product when examined gave at first from 85 to 90 parts boiling under 100°, but in later experiments the result came up to 95 parts at 100° and 97 parts at 105°. This result, from the manufacturing point of view, was as perfect as we could desire.

It is not our wish to express any opinion as to the nature of the mixed gas, but can only record the fact, that it acts very much as we should expect nitrous acid gas (if it exists) would act upon amyl alcohol. That is a question, however, we leave for the consideration of others.

5. *On the Action of Water on Lead.* *By* A. H. Allen, *F.C.S.*

SECTION C.—GEOLOGY.

PRESIDENT OF THE SECTION—Professor J. W. JUDD, F.R.S., Sec. G.S.

THURSDAY, SEPTEMBER 10.

The PRESIDENT delivered the following Address:—

As this city is the only place within the limits of the Scottish Highlands where our Association holds its annual gatherings, it is fitting that the attention of those who meet in this Section should, on the present occasion, be specially directed to the grand problems of Highland geology. Six-and-twenty years have passed since the members of this Section assembled here, under the presidency of my dear friend, my revered master, Charles Lyell. Few now present can have actually listened to the stormy discussions of that memorable occasion, but all are familiar with the nature of the problems which in the year 1859 were here so keenly debated. It is true that the fires of these controversies have now almost died out, and from their ashes have arisen the new problems which confront us to-day; but it will not, I think, be without profit to direct your attention for a few minutes to those two subjects which constituted the 'burning questions' of that time—the age of the Crystalline Rocks of the Highlands, and the geological position of the Reptiliferous Sandstone of Elgin.

With respect to the first of these questions, there are especial reasons why I should briefly review the discussions which have taken place in connection with it. It was in the meetings of this Section of the British Association that the successive stages of the controversy were gradually developed. It was at a former meeting of the Association in this city that James Nicol submitted to the scientific world that splendid solution of a difficult problem, which is now universally admitted to have been the correct one. This university was, during the last twenty-seven years of his active, useful, and honoured life, the scene and centre of the labours of that profound but modest thinker to whom we owe so much. Lest it should seem presumption on my part to speak on the question, I may add that for some years before his death it was my good fortune to enjoy the friendship and confidence of the late Professor Nicol, with whom I had several opportunities of discussing the great questions at issue between himself and Murchison. Seeing, as I do to-day, his own great claims too often forgotten or ignored, I feel that should I, on this occasion, hold my peace—'the very stones would cry out.' It will indeed be an unfortunate day for our republic of science when the palm of recognition—withheld from him whom modesty and self-respect restrain from clamorous self-assertion—is permitted to be snatched away by the bold and noisy advertiser of his own claims.

Nearly seventy years ago, John Macculloch—that distinguished pioneer in Scottish geology—was able to prove that in our Western Highlands there exists a grand formation, made up of red sandstones and quartzite, both exhibiting unmistakable evidence of a sedimentary origin. He also pointed out that, associated with these red sandstones and quartzites, are beds of limestone, which are often altogether destitute of crystalline characters, and are sometimes bituminous, while they occasionally contain fossils.

Macculloch strongly insisted that this great system of strata, which covers large areas in Sutherland and Ross, extending also into some of the Western Isles, is distinct alike from the Old- and the New-Red Sandstone; he asserted that it belongs to a far older period than either of those formations, and, employing the phraseology of the early geologists, he gave to it the name of the '*Primary* Red Sandstone.'[1]

Macculloch showed clearly that the strata of his 'Primary Red Sandstone Formation' are often found resting unconformably upon the gneissose and schistose rocks of the Highlands; but that in other places they appear to be overlain conformably by, and even to alternate with, crystalline schists and gneisses. He was further able to state that the quartzites of his 'Primary Red Sandstone Formation' contain organic remains, some of which he correctly identified as the burrows of marine worms, while others he recognised as *Orthoceratites*.[2] It is almost painful to have to add that his want of appreciation of the value of palæontological evidence, a weakness which Macculloch shared with so many of the early Scottish geologists, prevented any attempt on his part at the correlation of this 'Primary Red Sandstone' with the rocks of other districts; and thus for more than forty years this important discovery remained almost entirely fruitless.

The next step in the history of our knowledge of these Highland strata which we have to record, was unfortunately a retrograde one. Sedgwick and Murchison, who visited the district in 1827, maintained that Macculloch had fallen into grievous error, and that his 'Primary Red Sandstone Formation' was in fact no other than an outlying part of the Old Red Sandstone.[3]

This view was strongly protested against by Hay Cunningham, who, writing in 1839, after a careful survey of Sutherland, demonstrated the justice of Macculloch's conclusions, and even went beyond that geologist in showing the very intimate connexion between the quartzite and limestone. He clearly illustrated by numerous sections the unconformity of the 'Primary Red Sandstone Formation,' consisting of red sandstone, quartzite, and limestone, upon the gneissose rocks, and the apparently conformable superposition to it of other schists and gneisses.[4]

Such was the state of geological opinion when, in the winter of 1854, the attention of geologists was recalled to this ancient formation of Macculloch by the discovery in it of fossils by one who fully recognised their value and importance—Mr. Charles Peach. These fossils, though imperfect, were sufficient to prove that the strata containing them must be of *Palæozoic* age.

Three of the leaders of geological science at that day appear to have been deeply impressed with the importance of this discovery of Mr. Peach's; but for a time, at least, the fruits of that discovery were missed, through the unfortunate retrograde teachings of Sedgwick and Murchison in 1827.

Hugh Miller, whose splendid researches in the Old Red Sandstone had made him ready to welcome any extension of its boundaries, suggested that the fossils of Durness might belong to the marine Devonian.

Roderick Murchison, who in his younger days had worthily conquered a kingdom in Siluria, and by successive annexations in his later years had sought to convert this kingdom into an empire—one which should embrace all the Lower Palæozoic rocks of the globe—was not unwilling to claim his native Highlands as part of this ever-growing realm.

James Nicol, who had been the first to discover graptolites in the rocks of the Scottish Borderland, and had thus demonstrated their Silurian age, was so struck by the resemblance of some of the slaty rocks of the Highlands to the fossiliferous shales of his native district, that, ten years before Peach made his important discovery, he had suggested the probability of the Highland schists and gneisses being

[1] *Trans. Geol. Soc.* ser. 1, vol. ii. p. 450, &c. *Western Isles of Scotland* (1819), vol. ii. p. 89, &c. *System of Geology* (1831).

[2] *Western Isles of Scotland* (1819), vol. ii. pp. 512, 513.

[3] *Trans. Geol. Soc.* ser. 2, vol. iii. p. 155.

[4] 'On the Geognosy of Sutherlandshire,' by R. J. H. Cunningham, M.W.S.; *Transactions of the Highland and Agricultural Society of Scotland*, vol. xiii. (1839).

simply the Borderland shales and greywackes in an altered state.[1] Hence Nicol, equally with Murchison, was prepared to accept the Silurian age of the Durness limestone, and of the rocks associated with it.

Murchison, still full of his old enthusiasm for discovery, determined to lose no time in putting to the test the truth of the suggestion made by his old friend Nicol and himself; and accordingly shortly before the meeting of the British Association, which was fixed to take place in the year 1855 at Glasgow, we find the two friends making their way into the wild district of North-west Sutherland.

Unfortunately the time was too short and the weather too unpropitious for the tasks they had set before themselves.

When this Geological Section assembled at Glasgow, Murchison declared his conviction that the limestone of Durness, which had yielded the fossils to Mr. Peach, was of Silurian—that is, as he employed the term, of Lower Palæozoic age. But he, at the same time, maintained the truth of his old views, that the red sandstones of Applecross and Gareloch are in reality nothing but Old Red Sandstone,[2] and in this latter contention he received the warm support of Sedgwick, who was also present at the meeting.[3]

Nicol, on the other hand, appears to have been greatly dissatisfied with the results of this hasty and inauspicious journey to Sutherland. While, however, withholding his judgment as to the age of the several rock-masses, he insisted, in opposition to the views of Murchison and Sedgwick, that the whole of the vast series of Red Sandstones in Applecross and Torridon is, as Macculloch showed, inferior to the quartzite and limestone.[4]

In the summer of the next year, 1856, Nicol, so soon as he was released from his teaching work in this university, hastened back to the Western Highlands to try and resolve some of the doubts which troubled him concerning the age and succession of the strata. This summer's labour was productive of great and important discoveries. In the first place, he was able to completely confirm the conclusion of Macculloch and Hay Cunningham, that *all* the Red Sandstone of the Western Highlands, with the exception of some small patches of 'New Red,' belong to an old formation underlying the quartzite and limestone. But his researches also enabled him to show that Macculloch's 'Primary Red Sandstone' in reality consists of *two* formations, the lower—to which he subsequently gave the name of the 'Torridon Sandstone'—lying unconformably on the gneiss, and the upper (consisting of quartzite and limestone, containing fossils), resting everywhere unconformably upon, and overlapping, the sandstones.[5] It is a very noteworthy circumstance that while Nicol admitted the accuracy of the descriptions of Macculloch and Hay Cunningham which seemed to point to a conformable superposition of beds of gneiss to the quartzite and limestone, the results of this first summer's work had already raised serious misgivings in his mind as to the correctness of this conclusion, for he wrote as follows:—'The fact of the overlying gneiss having been metamorphosed *in situ*, and not pushed up over the quartzite, is one requiring further investigation.'[6] It is not surprising, however, to find that Nicol was so staggered by the magnitude of the faults which would be required to bring about such a result, that for more than a year he hesitated to accept this, which we now know to be the true explanation of the phenomena.

There was a suggestion—and it was nothing more than a suggestion—made by Nicol at this time, which has often been very unfairly quoted to his disadvantage. Convinced that Macculloch was right as to the infraposition of the Torridon Sandstone to the quartzite and limestone, and strongly inclined to accept

[1] *Guide to the Geology of Scotland* (1844).

[2] *Brit. Ass. Rep.* 1855; *Trans. of Sec.* p. 87.

[3] Geikie's *Memoir of Sir Roderick Murchison* (1875), vol. ii. p. 207.

[4] See Nicol's *Geology of the North of Scotland* (1866), Appendix, p. 96.

[5] Col. Sir Henry James is said to have made similar observations during the same season, the summer of 1856, and to have communicated them to Sir Roderick Murchison by letter. But there can be no doubt that Nicol's discovery was made quite independently, and he was the first to publish it.

[6] *Quart. Journ. Geol. Soc.* vol. xiii. (1857), p. 35.

Murchison's confident assertion that this Torridon Sandstone was simply the 'Old Red,' Nicol pointed out that the only possible way of harmonising these two views was to suppose that the quartzites and limestones were of Carboniferous age; and he showed that the imperfect fossils which had been up to that time obtained at Durness were not sufficient to negative such a supposition.[1]

But during the summers of 1857 and 1858, Nicol continued his labours in the Western Highlands, with the result of clearing away many of his difficulties and perplexities. Murchison, too, had revisited the district, and seen that his idea of the 'Old-Red' age of the Torridon Sandstone would have to be finally abandoned, and that Macculloch's views, as amended by Nicol, concerning the relations of the Highland rock-masses must be accepted. Salter, too, examining more perfect specimens of fossils, which had in the meanwhile been obtained from the Durness limestone by the indefatigable Mr. Charles Peach, showed that they were certainly of *lower* Palæozoic age (Silurian of Murchison).

The position taken up by Murchison, and on which he made his final stand, was simply arrived at by combining the stratigraphical conclusions of Macculloch and Nicol with the palæontological results of Peach and Salter.

Murchison attended the meetings of this Association at Dublin in 1857, and at Leeds in 1858, on both occasions making use of the opportunity for explaining in detail his ideas concerning the age and succession of the Highland rocks. On the latter occasion, he challenged his old friend Nicol to meet him at the forthcoming meeting at Aberdeen to discuss the question, and the challenge was accepted.

When Murchison arrived at this city, in September 1859, he brought with him a redoubtable champion in the person of Professor (now Sir Andrew) Ramsay, the director of the Geological Survey, who had been conducted to Assynt and shown the section there. It may perhaps serve as a caution against hasty generalisations, drawn from a single section imperfectly examined, to remember that so excellent a field-geologist, as Ramsay undoubtedly was, not only failed to see the weakness of Murchison's position, but threw all the weight of his great authority into the scale against Nicol in this memorable controversy.

Nicol, however, laid before this meeting a paper which, afterwards published in detail in the Journal of the Geological Society,[2] must be admitted to have really established the main facts concerning the geology of the Highlands as accepted by all geologists at the present day; though his views, as is not uncommonly the case with great and original discoveries, were met for a long time with nothing but bitter opposition or cold neglect. Permit me to state, as briefly as possible, the conclusions which Nicol, as the result of three years of patient work in the Western Highlands, was able to announce in this place, just twenty-six years ago.

1. He maintained with Macculloch and Hay Cunningham, and in opposition to the views originally propounded by Sedgwick and Murchison, that there exists in the Western Highlands an enormously thick series of red sandstones, quartzites, and limestones, which rest uncomformably upon the ancient gneisses and schists, and belong to a far older geological period than the Old Red Sandstone.

2. He showed that this series of strata really constitutes *two* distinct formations, and that the older of these, the Torridon Sandstone, consists of red sandstones and conglomerates, in which no organic remains could be detected.

3. The younger of these formations was shown by him to lie unconformably upon the Torridon Sandstone, and to consist of three members, which Nicol named the Quartzite, the Fucoid Beds, and the Limestone.[3] It is this formation which has yielded the interesting fossils of Lower Palæozoic age.

4. The apparent repetition of beds of quartzite and limestone, which was insisted upon by Murchison, was shown to be due to faulting and overthrow, and thus the

[1] *Quart. Journ. Geol. Soc.* vol. xiii. (1857), p. 36.

[2] *Quart. Journ. Geol. Soc.* vol. xvii. (1861), pp. 85–113. This paper was read on December 5, 1860; although its title is slightly different, the whole course of the argument is the same with that of the paper read here in the September of the previous year.

[3] *Quart. Journ. Geol. Soc.* vol. xvii. (1861), p. 92, &c.

'Upper Quartzite' and the 'Upper Limestone' of that author were proved to have no real existence.[1]

5. What so many authors had taken for a conformable upward succession of this older Palæozoic formation into overlying schist and gneiss, was asserted by Nicol to be an altogether fallacious appearance, due to the thrusting of the crystalline rocks over the sedimentary ones by great overthrow-faults.

6. The relations between these crystalline and sedimentary strata in the Scottish Highlands were shown to be precisely similar to those which are constantly produced by lateral pressure in all great mountain-chains, and consist of sharp foldings, inversions, and faulting on the very grandest scale. Examples of overthrow-faults, similar to those of the Scottish Highlands, were instanced by Nicol as occurring in the Alps.[2]

We cannot perhaps better illustrate the position maintained by Nicol in this remarkable paper than by quoting the following passage:—'Until some rational theory is produced of the mode in which an overlying formation, hundreds of square miles in extent and thousands of feet in thickness, can have been metamorphosed, whilst the underlying formation of equal thickness and scarcely less in extent has escaped, we shall be justified in admitting inversions and extrusion' (*i.e.*, of older masses on younger, as he explains his meaning to be) 'equal to those of the Alps.'[3]

The only serious error into which Nicol fell—and after all it is a very inconsiderable one judged in comparison with his undoubtedly great achievements—was that of attaching too much importance to the influence of igneous intrusions in connection with the tremendous inversions and overthrow-faults to which he so clearly showed that these Highland rocks have been subjected. We now know that many of these supposed intrusive masses, though really of igneous origin in all probability, were of *older* date than the Palæozoic rocks in the midst of which they lie; and that they were brought into their present positions, not by intrusion in a liquid state, but by complicated faulting. It must be remembered that these 'granulites,' as Nicol very justly called them,[4] for they present a wonderful analogy with the typical rocks of Saxony which are known by that name, have long been regarded by geologists as among the most difficult and perplexing of rocks to explain the origin of, though the recent researches of Dr. Lehmann have now done something towards the solution of the problem.

Calmly reviewing, in the light of our present knowledge, the grand work accomplished single-handed by Nicol, I have no hesitation in asserting that when this Association met here twenty-six years ago, he had already mastered the great Highland problem in all its essential details, and that his results were distinctly proclaimed during the meetings of this Section.

If, then, Nicol had so fully solved this great problem of Highland geology twenty-six years ago, how is it, may not unreasonably be asked, that we have waited so long for the justice of these views to be admitted?

A variety of circumstances have contributed to bring about this unfortunate result. Murchison was at the time too old and infirm to examine in careful detail the wild districts where these rock-masses are exhibited. Hence Nicol's oft-repeated invitations to view the sections in his company remained unheeded, and we find the great geologist of Aberdeen writing in 1866 his concluding plaintive words in this memorable discussion: 'I must express my most sincere regret that my illustrious opponent—from whom only the most thorough conviction that my views are well founded, and that the question was one on which it became a teacher of geology in Scotland to give no uncertain utterances, could have compelled me to differ—has never found it convenient to meet me again in the North. I am convinced that we agree in so many essential points, that a few hours together in the field would bring us nearer in opinion than whole volumes of controversy.'[5]

The phalanx of eminent geological authorities opposed to the views of Nicol,

[1] *Quart. Journ. Geol. Soc.* vol. xvii. (1861), pp. 98, 108, 109, &c.
[2] *Ibid.* pp. 108, 109, 110. [3] *Ibid.* p. 110.
[4] *Ibid.* p. 89. [5] *Geology of the North of Scotland*, p. 96.

including Professors Harkness, Ramsay, Archibald Geikie, and Hull, for a long time carried all before them; but it is now admitted that each of these excellent observers was deceived by having seen only portions of the evidence, and that they based their conclusions on imperfect data. Nicol, though during the later years of his life he declined unavailing controversy, still continued to study the Highlands year by year, re-examining every joint in his armour and satisfying himself of its soundness.

In the year 1877 I had an opportunity of visiting for the first time the interesting sections of Assynt and Loch Broom, in company with Dr. Taylor Smith, F.G.S., and Mr. Richard D. Oldham, now of the Geological Survey of India. Although I entered upon this task with the strongest prepossessions in favour of the Murchisonian hypothesis, yet what I saw there during several weeks of work convinced me that the theory of an 'Upper Quartzite' and an 'Upper Limestone' was altogether untenable, and that, so far as these two sections were concerned, Nicol's interpretation was undoubtedly the correct one. I was greatly impressed with the proofs of enormous folding and faulting among these Highland rocks, and when, shortly afterwards, I had an opportunity of meeting Professor Nicol in this place, and of hearing from his lips many details of his later work, I strongly urged him to republish his conclusions with the fuller illustrations and arguments which he was then so well able to supply. To all my pleadings he made but one reply: important as he knew these discoveries to be, yet in his advancing years he thought but little of the glory of them compared to their painful consequences to himself—the breach of the old friendly relations with one he, to the end, so greatly loved and honoured. He strongly deprecated at that time the re-opening of a controversy associated for him with such bitter memories; but he expressed his full conviction that when sufficiently accurate topographical maps were in existence, and the whole district should be surveyed by competent geologists, the truth of all the essential parts of his teaching would be established.[1]

Most completely have these anticipations of Nicol been fulfilled. During the last seven years many of the sections of the Western Highlands have been visited by different geologists, Dr. Hicks leading the way, and not a few papers have been published embodying the results of these new studies of some of the disputed points. Such an able review of this recent work has been lately drawn up by my friend, Professor Bonney, in his Anniversary Address to the Geological Society, that I need not go over the ground again, but will content myself by referring to that address and to two exhaustive papers read by Dr. Hicks before the Geologists' Association for full details concerning this later work. It will be seen that while new methods of study have enabled them to improve or correct Nicol's petrological nomenclature, the principal conclusions of nearly all these writers concerning the relations of the several rock-masses entirely support his views on the subject.

But very recently Nicol's work has been tested in the way which he himself so earnestly desired. Professor Lapworth, who, like Nicol, was especially prepared for the task by long and patient study of the crumpled Silurian rocks of the Borderland, taking advantage of the newly-published Ordnance maps of Sutherland, proceeded in the summer of 1882 to Eriboll, bent on the task of unravelling the complicated rocks and of mapping them upon the large scale of 6 inches to the mile. Professor Lapworth's detailed maps and sections were exhibited to the Geological Society on May 9, 1883, during the reading of a paper by Dr. Callaway, in which the views of Nicol also received a considerable amount of valuable support.

In the same year, 1883, a detachment of the Geological Survey of Scotland, under the superintendence of Messrs. B. N. Peach and J. Horne, commenced the detailed mapping of the Durness-Eriboll district. How admirably these gentlemen have performed their task we all know, and I hope that some interesting information

[1] In my two earlier papers 'On the Secondary Rocks of Scotland,' published in 1873 and 1874 respectively, I had employed the Murchisonian nomenclature for the older rocks of the Highlands whenever I had occasion to refer to them; but in the third of this series of papers, published in 1878 (*Quart. Journ. Geol. Soc.* vol. xxxiv. p. 660), I had no hesitation in abandoning this terminology for that of Nicol.

concerning their conclusions will be laid before the present meeting. In offering them—as I am sure that I am empowered by you to do—the hearty congratulations of the Geological Section of the British Association upon the auspicious commencement of this great undertaking, I cannot refrain from reminding you that, of the leaders in this important enterprise, one is the son of the discoverer of the Durness fossils, the veteran Mr. Charles Peach to whom we owe so much, while the other is a very active and efficient local secretary of this Section.

Nor should I do justice to my own sentiments on the subject, if I failed to bear tribute to the judgment displayed by the present chief of the Geological Survey in his choice of a base from which to attack this difficult problem, to his loyalty in accepting results so entirely opposed to his published opinions, and to his promptitude in making his fellow-workers in geology acquainted with these important discoveries. Unfortunately called upon while still young, and with but little of that ripe experience which he has since gained, to grapple with the most intricate of problems—problems which the most practised of field-geologists might be forgiven for failing to solve—his own judgment yielded, though not without serious misgivings,[1] when opposed to the ardent confidence of a companion and friend, whose reputation in the scientific world commanded his respect, and whose previous achievements had won his complete reliance. If, like your own Randolph at Bannockburn, he has 'lost a rose from his chaplet' at the commencement of this great Highland campaign, we are well assured that the error will be worthily repaired in its subsequent stages.

The conclusions arrived at by Nicol, by Professor Lapworth, and by the officers of the Geological Survey concerning the relations of the rock-masses in the north-west of Sutherland, are, in all their main features, absolutely identical; and the Murchisonian theory of Highland succession is now, by universal consent, abandoned.

In the second of the great controversies to which we have alluded as having occupied the attention of this Geological Section in 1859—that concerning the age and relations of the Reptiliferous Sandstone of Elgin—the combatants were found ranged in quite a different order. Nicol is seen battling shoulder to shoulder with Murchison, Ramsay, and Harkness, in favour of the *Palæozoic* age of the beds in question; while Lyell, supported by Symonds of Pendock and Moore of Bath, is as stoutly maintaining their *Secondary* age.

The finding by Mr. Patrick Duff, in the year 1852, of the little fossil lizard called *Telerpeton*, and the determination of its true nature by Mantell and Owen, constitute a discovery comparable in importance and fruitfulness to Mr. Peach's detection of the fossiliferous character of the limestone of Durness; up to that time no doubt had ever been entertained as to the 'Old Red' age of the yellow sandstone of Elgin. For bringing together the remarkable fossils of these rocks, geologists are indebted to the untiring labours of Dr. Gordon of Birnie—whom, full of years and honours, and the object of such universal respect and love as indeed make grey hairs a 'crown of glory,' we rejoice to have still in our midst. Studying Dr. Gordon's important collections, Professor Huxley was able, shortly before the previous meeting of the Association in this city, to announce that a crocodilian (*Stagonolepis*), and a second lizard of Triassic affinities (*Hyperodapedon*), existed at the period when these beds were deposited, so that even in 1859 the palæontological evidence in favour of the Mesozoic age of these rocks was admitted to be almost overwhelming.

But this evidence has been very greatly strengthened since that date; for Professor Huxley has shown that the genus *Hyperodapedon* is represented in the Trias of Warwickshire, of Devonshire, and of India. In the same reptiliferous sandstone, with its abundant footprints, there have been found the remains of a reptile which Professor Huxley permits me to state is, in his opinion, probably *Dinosaurian*. I am sure that you will all join with me in the hope that the health of the President of the Royal Society may soon be so far restored that he may be able to return to the examination of these fossil reptiles of Elgin, in the study of

[1] See *Memoirs of Sir Roderick Murchison* (1875), vol. ii. p. 238.

which some of the earliest of his great palæontological discoveries were achieved. Within the last few days the remains of another reptile, clearly referable to the *Dicynodontia* has been found; so that no less than four orders of reptiles are now known to be represented in the formation.

The manner in which the yellow sandstones, which have yielded these reptilian remains, are at many different points found associated with beds containing *Holoptychius* and other Old Red Sandstone fish, appeared to many geologists altogether inexplicable on any other hypothesis than that the strata are all of the same geological age.

In spite, however, of these appearances, and the interesting observations of Dr. Gordon and Dr. Joass on the rocks of the Tarbet peninsula, which seemed to support the hypothesis just referred to, I am able to announce that proof of the most clear and convincing character now exists of the distinction between the fish-bearing 'Old Red' and the reptiliferous 'New Red' of the neighbourhood of Elgin. In the year 1873 I showed that rocks, identical in character with the reptiliferous sandstone of Elgin, and the overlying calcareous and cherty rock of Stotfield, exist on the northern side of the Moray Firth, in the county of Sutherland, and that they there conformably underlie Rhætic and Liassic strata. Very recently Dr. Gordon has added a crowning discovery to his long list of previous ones, by detecting in the same quarry the rocks containing the reptilian and fish remains respectively. I find, however, that while the two series of beds present well-marked differences in their mineral characters, the yellow sandstones with fish remains clearly overlie the undoubted Upper Old Red, and are separated from it by a well-marked bed of conglomerate. In other quarries in the district, the manner in which these two series of strata have been thrown side by side by the action of great faults is very clearly exhibited. I hope that full details of the evidence on this interesting subject will be laid before you during the present meeting.

The facts relied upon by the Palæontologist and the Stratigraphist respectively are thus found to be no longer opposed to one another. By a complicated series of parallel faults, the Devonian and Triassic sandstones, which happen to have a general resemblance in their mineral characters, are found again and again thrown side by side with one another in the Elgin district, so that the error into which geologists fell before the discovery of the distinctive fossils of the two sets of rocks, was a very pardonable one.

A retrospect of these two controversies, now so happily laid at rest, is not, I think, without its uses for the student of Highland geology, for it may serve to furnish him with some useful warnings which are in great danger of being overlooked at the present time.

The discovery of a few fossil remains in strata where they were previously unknown, has completely revolutionized our ideas concerning the age of rock-masses of enormous extent and thickness. Resemblances in mineral character have been proved not only to have been, at their best, very unsafe guides indeed, but to have actually betrayed those who trusted in them into the most serious errors. But for the discoveries of Charles Peach on the one hand, and of Patrick Duff and Dr. Gordon on the other, geologists would probably still continue to class the sandstones of Torridon and Elgin respectively with the 'Old Red.'

But perhaps the consideration of greatest importance which is impressed upon us by this retrospect is, that in these Highland districts we must be always prepared to meet with rock-masses of very different geological ages, thrown into puzzling juxtaposition by the gigantic movements to which this part of the earth's crust has been subjected. He who enters on the study of Highland geology without being prepared to encounter at every step complicated foldings, vast dislocations, and stupendous inversions of the strata, can scarcely fail to be betrayed into the most disastrous and fatal errors.

The early history of Scotland is inextricably interwoven with that of Scandinavia. This proposition, true as it is of the insignificant periods of which human history takes cognizance, applies with even greater force to the vast epochs that fall within the ken of the geologist. To us the separation of Scotland and

Scandinavia is an event of very recent date indeed; it is not only an accident, but an uncompleted accident! The Scottish Highlands, with the Hebrides and Donegal on the one hand, with Orkney and Shetland on the other, must be regarded—to use a technical phrase—as mere 'outliers' of the Scandinavian Peninsula.

We must acknowledge, at the outset, that the study of the geological history of this Scandinavian peninsula and its outliers is a task bristling with difficulties. The problems presented to us in our Scottish Highlands are vast, complicated, and at times seemingly insoluble. But they are precisely the same problems that confront our brother geologists in Scandinavia. And if our tasks, our doubts, our perplexities are the same, we equally share in the advantages and triumphs of discovery.

The geologists of Scandinavia—and right worthy sons of Thor they are—have the advantage of possessing a territory almost limitless in its vastness, and seemingly infinite in its variety. But the very extent of their splendid country, with its sparse population and restricted means of communication, increases the difficulties of their task. 'The harvest truly is plenteous, but the labourers are few!' With our smaller area, if we cannot expect so much variety, we may hope to gain something from the number of our students and the greater accessibility of our fields of labour.

Nor would I undervalue, in this connection, the importance of the union of this country with England. I allude, of course, not to events of yesterday, like the Accession of James VI. to the English throne and the Parliamentary Act of Union, but to operations that preceded these by many millions of years! It is no small advantage that a country like Scotland, in which the rock-formations are found hopelessly crushed and crumpled together, or broken into a thousand ill-fitting fragments that seem to defy all attempts to reduce them to order, should be united to one like England, where, by comparison, all is orderly and simple, the strata lying in regular sequence like well-arranged volumes in a library, and only await the touch of the geologist's hammer to display the wealth of their fossil contents.

The great Scandinavian *massif*, with its outlying fragments, constitutes the 'basal-wreck'—to employ Darwin's expressive term—of a great Alpine chain. On other occasions I have endeavoured to show how much our study of the nature and products of volcanic action is facilitated by the existence of similar 'basal-wrecks' of volcanic mountains, like those which exist in your beautiful Western Isles. In the same way, I believe we may learn more by the study of this dissected mountain-chain, concerning the operations by which these grand features of our globe have originated, than by the most prolonged examination of the superficial characters of the Alps or the Himalayas.

Here the scalpel of denudation has laid bare the innermost recesses of the mountain-masses, and what we can only guess at in the Alps and the Himalayas, here stands in our own Highlands clearly revealed to view.

It is a well-ascertained fact that all the existing lofty mountain-chains have been formed at a very recent geological period. The reason of this it is not difficult to divine. In the higher regions of the atmosphere, the forces of denudation work so rapidly that within a very short period—geologically speaking—the vastest mountain-chain is razed to its very foundations—

> They melt like mists, the solid lands,
> Like clouds they shape themselves, and go!

It is not surprising then to find Powell and Gilbert, fresh from the study of the grand mountain-masses of the American Continent, giving expression to these thoughts in the following words: 'All large mountains are young mountains, and, from the point of view of the uniformitarian, it is equally evident that all large mountains must be growing mountains; for if the process of growth is continuous, and if a high mountain melts with exceptional rapidity before the play of the elements, it is illogical to suppose that the uprising of any mountain, which to-day is lofty, has to-day ceased.'

The Scandinavian Alps were a living and a growing mountain-chain in the far-

distant Palæozoic period. Now it is not only dead, but stretched on the dissecting-table of the geologist—its outer integuments and softer tissues stripped away, and its very skeleton bared to our view—a splendid 'subject' for the student of mountain anatomy.

One of the first to recognise this value of our Scottish Highlands to the student of Orographic Geology was the late Daniel Sharpe. He had made himself familiar with many of the characteristic details of Alpine architecture—so far as it was then understood—and was able to show that the foliated masses of our Highland districts exhibit precisely those relations which would be seen if the contorted and fan-like masses of the Alps were planed away by denudation. Nor in suggestions of this kind, as we have seen, was James Nicol far behind Sharpe; but at that time many of the most important features of mountain-structure were unrecognised or misinterpreted, and the conclusions of these geological pioneers were little more than guesses—though very valuable and suggestive guesses—after truth.

It is to our geological brethren over the Atlantic that we are especially indebted, not only for many important discoveries in the mechanics of mountain-formation, but for clearing away many of the clouds of error in which the subject had become involved. To Henry Darwin Rogers, who, after a career of valuable geological work in his native State of Pennsylvania, accepted the hospitality of this country, and spent the last decade of his useful life as Professor of Natural History and Geology in the sister university of Glasgow, must be assigned the foremost place in that school of orographic geologists which has grown up in America.

The first sketch of the important theory of mountain-building, to which Rogers and his fellow-geologists were led by the study of the Appalachian chain, was published in 1842, but it was not till 1858 that the complete evidence on which this theory was founded could be published.

The conclusion at which Rogers arrived was, briefly expressed, as follows:—The Appalachian mountains were carved by denudation out of an enormously thick mass of stratified deposits, thrown into a series of parallel wave-like folds. To the westward of the mountain range 'the crust-waves flatten out, recede from one another, and vanish into general horizontality;' but towards the heart of the mountain-mass the same flexed strata become greatly crowded together, their 'axis-planes' become more and more inclined, till at last their folds, yielding at their apices to the tremendous lateral thrust, fractures twenty to eighty miles in length, and attended with a displacement of 20,000 feet or more, were produced.

Unfortunately Rogers accompanied these just views of mountain structure with certain crude speculations and untenable hypotheses concerning the methods by which they were produced. But in the minds of other American geologists, among whom may especially be mentioned Dana, Le Conte, and Vose—the fruitful ideas of Rogers have undergone development and expansion, while they have received abundant illustration through the labours of that active band of pioneers—the United States Geological Survey—including Clarence King, Powell, Emmons, Hague, Dutton, Gilbert, and many others.

Nor have the brilliant results attained by these investigators in the New World been without their effect on the geologists of Europe. Lory, Suess, Heim, Baltzer, and others have shown that the clue to the right understanding of the structure of the Alps, which had been so diligently sought and so long missed by Von Buch and De Beaumont, by Studer and Favre, was now placed in our hands by the researches of the American geologists.

In Northern Europe, Kjerulf, Dahll, Brögger, Reusch, and other geologists have ably illustrated the same peculiarities of structure in the denuded mountain-chain near the southern extremity of which we are now assembled; and in a recent valuable and suggestive essay 'On the Secret of the Highlands' Professor Lapworth has shown how perfectly these structures are exemplified in the western district of Sutherland.

In offering a few remarks on some of the still unsolved problems of Highland geology I shall not hesitate to treat, as belonging to the same geological district, both Scandinavia and Scotland. Not only is the succession of geological deposits in the two areas almost completely identical, but the characters of the several

formations and their relations to one another in the one country are almost the exact counterpart of what they are in the other.

The problems which await solution in Scotland are the same which confront our brethren in Scandinavia; their difficulties are our difficulties, their successes our successes; if they share the benefits of our discoveries, we equally partake with them in the fruits of their achievements. Important links in the chain of geological evidence, absolutely wanting in the one area, may perchance be found in the other. Every advance, therefore, which is made in the knowledge of the rocks of the one country, must necessarily re-act upon the opinions and theories which prevail among geologists in the other.

At the base, and forming the foundation of this greatly denuded mountain-chain, there exist enormous masses of highly foliated, crystalline rocks. These, in great part at least, underlie the oldest known, fossiliferous strata, and are therefore of pre-Cambrian or Archæan age. In spite of the labours of Kjerulf, Dahll, Brögger, Reusch, Torneböhm, and many others in Scandinavia, and of Macculloch, Nicol, and their successors in this country, much still remains to be done in studying the petrographical characters and the geognostic relations of these widespread formations.

Some thirty years ago it was suggested by Sir Roderick Murchison that among these Archæan rocks there exists a 'fundamental gneiss,' a formation which is the counterpart and contemporary of the rocks in Canada, to which Sir William Logan gave the name of 'Laurentian.' Since that time other similar attempts have been made to identify portions of these Archæan rocks in the Highlands and Scandinavia with crystalline rock-masses in different parts of the New and Old World.

I confess that, speaking for myself, I am not sanguine as to the success of such endeavours. The miserable failures which we have seen to have attended similar attempts, in the case even of far less altered rocks, where identifications have been based on mineralogical resemblances only (and in connexion with which definite palæontological or stratigraphical evidence has been subsequently obtained) ought surely to teach us caution in generalising from such uncertain data. It has been argued that, where palæontological evidence is wholly wanting, and stratigraphical relations are doubtful or obscure, then we may be allowed to avail ourselves of the only data remaining to us—those derived from mineralogical resemblances. But surely, in such cases, it is wiser to admit the insufficiency of the evidence, and to say 'We do not know!' rather than to construct for ourselves a 'fool's paradise,' with a tree of pseudo-knowledge bearing the Dead-Sea fruit of a barren terminology! The impatient student may learn with the blind poet that

They also serve, who only stand and wait.

It is thought by some that the application of the microscope to the study of rock-masses may reveal peculiarities of structure that will serve as a substitute for palæontological evidence concerning the age of a rock when the latter is wanting. Greatly as I value the insight afforded to us by the microscope when it is applied to the study of the rocks, and highly as I esteem the opinions of some of those who hold these views, yet I fail to see that any such connection between the minute structure and the geological age of a rock has as yet been established.

Although the bold generalisation which sought to sweep all the crystalline rocks of our central Highlands into the great Silurian net has admittedly broken down, yet it by no means follows that the whole of these rock-masses are of Archæan age. Nicol always held that among the complicated foldings of the Highland rocks many portions of the older Palæozoic formations, in a highly altered condition, were included.[1] The same view has been persistently maintained by Dr. Hicks, to whose researches among the more ancient rock-masses of the British Isles geologists are so greatly indebted, and also by Professor Lapworth.

To the settlement of this very important question we may feel sure the effort

[1] See *Quart. Journ. Geol. Soc.* vol. xix. (1864), p. 184, and *Geology and Scenery of the North of Scotland* (1866).

of the officers of the Geological Survey will be especially directed. The geological surveyors of Scandinavia have been so fortunate as to detect, in rocks of an extremely altered character, a number of fossils sufficiently well preserved for generic and sometimes even for specific identification. Failing the occurrence of such a fortunate accident, I confess that it has always appeared to me that the disturbances to which these Highland rocks have been subjected are so extreme, and the difficulty of making out the original planes of bedding so great, that but little can be hoped for from general sections constructed to show the relations of the rocks of the Central and Southern Grampians to the fossiliferous deposits of the North-West of Sutherland.

Lying unconformably upon these Archæan crystalline rocks in our North-West Highlands we find great masses of arkose or felspathic grit, with some conglomerates, the whole of these well-stratified deposits attaining a thickness of several thousands of feet. These rocks, in their characters and their relations, so greatly resemble the 'Sparagmite Formation' of Scandinavia, that it is impossible to refrain from drawing comparisons between them. The Scandinavian formation, however, includes calcareous and slaty deposits, which are wanting in its Scottish analogue. The 'Sparagmites' of Scandinavia, as a whole, appear to underlie strata containing Cambrian (Primordial) fossils, but in the very highest portion of the 'Upper Sparagmite Formation' of Southern Norway there have been found, according to Kjerulf, specimens of *Paradoxides.*

The Scottish formation has, on the other hand, yielded no undoubted organic remains. Murchison, on the ground of its unconformable infraposition to his Silurian strata, and its resemblance to certain beds in Wales which he called Cambrian, referred it in his later years to that system. Although an identification, based on such grounds, must be admitted to be of small value indeed, yet the discovery of 'Primordial' fossils in the very similar rocks of Scandinavia may be admitted to lend it some slight support. In the present state of our knowledge, however, it is surely wiser to admit that the question of the age of these beds is still an open one, and to call it by the name suggested by Nicol—'The Torridon Sandstone.' Kjerulf believes there is evidence that the Scandinavian Sparagmite, in places, passes horizontally into true gneiss, and similar appearances are not wanting in the case of our Torridon Sandstone.

Concerning the overlying formation of quartzites and limestones, much yet remains to be made out. Nicol, Lapworth, and the officers of the Geological Survey, have shown it to be made up of three principal members—the identity of which cannot be mistaken although different names have been assigned to them. While Nicol estimated the total thickness of this formation at from 300 to 800 feet, however, and Lapworth places it at the smaller of these amounts, the officers of the Survey believe it to be no less than 2,000 feet thick.

Even greater uncertainty still exists as to the exact geological age of this important formation. Murchison, who in his later years made 'Silurian' a mere synonym for Lower Palæozoic, was no doubt right in regarding these rocks as being of that age. I have no intention of attempting to flog that dead horse—the controversy concerning the names which should be applied to the great systems containing the three faunas which Barrande so well showed to be present in the Lower Palæozoic rocks. That controversy, commencing, it must be confessed, with some tragic elements, has long since passed into the sphere of comedy, and now bids fair, if still persisted in, to degenerate into farce. Little, if anything, has been added to the work of Salter in connection with these fossils of the Durness limestone. With their abundance of that remarkable and aberrant mollusc, *Maclurea*, they can be paralleled with no other British or even European deposit, unless it be the Stinchar limestone of the Girvan district. Salter thought that this remarkable Scotch formation had its nearest analogues in the Calciferous sandstone and the Chazy limestone of North America. As those rocks contain 'Primordial' forms of Trilobites, they must probably be regarded as either of Cambrian age, or as constituting a link between the rocks containing Barrande's first and second faunas respectively. Under these circumstances, it is a piece of welcome intelligence that the officers of the Geological Survey have succeeded in obtaining a rich and

varied collection of organic remains from the beds of Sutherland; and the results of the examination and discussion of these fossils will be awaited by all geologists with the greatest interest.

Whether, as in case of Scandinavia, other fossiliferous deposits of Silurian age will be found to be represented in a highly metamorphosed condition in our Scottish Highlands, remains to be discovered. There is such a perfect parallelism between the several members of the Silurian in Scania and in the Scottish Borderland, so well shown by the researches of Linnarson and Lapworth, that, as Nicol always anticipated, we may not improbably find a portion of the rocks of the Highlands to be altered forms of those of the Borderland.

Since the last meeting of the British Association in the Highlands, much progress has been made in the study of that pre-eminently British formation—the Old Red Sandstone. Dr. Archibald Geikie has thrown much new light, by his valuable researches, on the relations of the several members of the vast series of deposits which go by that name; while Dr. Traquair, bringing to bear on the subject great anatomical knowledge, has re-examined the collections of fossil-fish made by that indefatigable explorer, Hugh Miller. The Old Red Sandstone is the only great system of strata which we possess, while it is either wholly absent, or very imperfectly represented, in Scandinavia.

In the year 1876, I was able to announce that a vestige—a small but highly interesting vestige—of the great Carboniferous system exists within the limits of the Scottish Highlands. Well do I recall the deep, the ineffaceable impression made upon my mind when, standing at the Innimore of Ardtornish, I beheld for the first time this relic of a great formation, preserved by such a wonderful series of accidents. What the inscribed stone of Rosetta or the papyri of Herculaneum are to the archæologist, this little patch of sandstone is to the geologist. Overwhelmed by successive lava-streams that were piled upon one another to the depth of many hundreds of feet, and then carried down by a fault which buried it at least two thousand feet in the bowels of the earth, this fragment has remained while every other trace of the formation has been swept from the Highlands by the besom of denudation.

Highly interesting and important in these northern areas are the Mesozoic deposits, which in places attain a vertical thickness of several miles, and which must have originally covered enormous tracts of country. Now, judged by that very fallacious test, the space which they cover upon our geological maps, they appear in the Scottish Highlands to be absolutely insignificant.

The correspondence in characters between the several Secondary formations on the two sides of the North Sea is of the most striking kind. I have had the good fortune to study the Secondary rocks of Scania under the guidance and with the assistance of Professor Lundgren, of the University of Lund, who has made so many important discoveries in connection with them. While doing so, I have again and again felt almost constrained to pause and rub my eyes, to convince myself that I was not back again in Scotland—so complete is the correspondence between the mineral characters, the fossils, and the geognostic relations of these strata in the two areas.

The Triassic rocks of Scandinavia, consisting of variegated sandstones and conglomerates, containing much calcareous material, are absolutely undistinguishable from those of the Western Highlands. In both countries the thickness of the deposits of this age varies within very short distances, their development being local and inconstant. The formation which in places exceeds a thousand feet in thickness, at other points is reduced to an insignificant band of conglomerate. On the eastern flank of our Highlands, yellow sandstones belonging to this formation have yielded to Mr. Duff, Dr. Gordon, Mr. Grant, and others that interesting series of reptilian remains which, in the hands of Professor Huxley, have been made to throw such important light on the forms of life which existed at that remote geological period. In the very similar deposits which occur in Scandinavia, however, reptilian remains have not as yet been obtained. The abundance and variety in form and size of the footprints which occur in our Scottish rocks of this age indicate the richness of the vertebrate fauna which must have existed at that distant epoch.

On both sides of the North Sea, the Triassic rocks are found passing up insensibly into the great formation known as the Rhætic and Infralias—a formation imperfectly represented in England and Central Europe by a few thin and insignificant strata, but in our Highland districts attaining a vast thickness and exhibiting a magnificent development. This system of strata consists of alternation of marine and estuarine deposits, the latter containing in both areas thin seams of coal. In Scania, the working of the coal and fire-clays of these deposits has brought to light vast numbers of fossil plants, which have been so well described by Nathorst. Several very distinct floras, occurring at different horizons, have been made out, and the relations of the beds containing these floras to one another, and to the marine strata with which they are intercalated, have been clearly demonstrated by the researches of Hébert, Erdmann, and Lundgren. That similar rich stores of fossil plants would reward a search as skilful and persevering as that made by our Scandinavian brethren, if carried on in the equivalent strata of Scotland, there can be little doubt.

The whole of the vast Jurassic system in these northern latitudes, attaining a thickness of 3,000 or 4,000 feet, appears to be similarly made up of alternations of marine and estuarine strata. Time would fail me to indicate even in the briefest manner the numerous problems of the highest interest suggested by the study of these vast deposits. At many different horizons, beds of coal and the relics of a rich terrestrial vegetation abound. Most of these await careful study and description. So far as they are yet known, the Ferns, the Cycads, and the Conifers of the Jurassic rocks of the Highlands present wonderful resemblances with those described by Heer from strata of the same age in Norway, in Russia, in Siberia, and even far away in the Arctic regions. The marine forms occurring in the associated strata seem to indicate that they belong to an ancient life-province, distinct from those in which the Jurassic rocks of Central and of Southern Europe were deposited. In the Upper Jurassic, so well represented in Sutherland by strata not less than 1,000 feet in thickness, we find evidence of the existence of mighty rivers, the banks of which, though clothed with tree-ferns, cycads, and gigantic pines, yet at certain seasons must have borne down ice-buoyed blocks of vast dimensions.

That the succeeding Neocomian period was for Scandinavia and Scotland an epoch of elevation and of the prevalence of terrestrial conditions is indicated by the total absence of any trace of marine deposits of this age, no less than by the enormous denudation which can be shown to have followed the Jurassic and preceded the Cretaceous period. Our now ruined mountain-chain then probably formed the lofty watershed of a great continent, through which flowed the mighty rivers that formed the deltas known as the English and German Wealdens.

How powerful and prolonged were the agencies of sub-aerial waste during this period is shown by the fact that the relics of the Cretaceous formation are found resting in turn on every member of the Jurassic, the Rhætic, the Trias, and all the different Palæozoic and Archæan rocks. A great portion, indeed, of the thick and widespread Rhætic and Jurassic strata seems to have been removed by denudation before the commencement of the Cretaceous period.

That thick strata of chalk once covered large areas of the Scottish Highlands and of Scandinavia we have the clearest proofs. In Scania and the adjoining parts of Denmark deposits of this age are found let down by tremendous faults, and these include even younger members of the series than are anywhere found in England. In the West of Scotland I have shown that thin deposits of Cretaceous age, preserved to us by a wonderful series of accidents, still survive the tremendous denudation of the Tertiary periods. It is true that in Scandinavia and Scotland alike, the chalk alternates with sandstones and even with strata of estuarine origin, but the pure foraminiferal rock that occurs in both areas could have been formed in no very shallow sea. That before the commencement of the great Tertiary denudation large areas, in Scandinavia and Scotland alike, must have been swathed in winding sheets of chalky rock there cannot be the smallest doubt. That considerable portions of these winding-sheets remained to so late a period as the glacial is shown by the fact that the indestructible flints of the chalk

with the rocks and fossils of the upper greensand abound in your boulder-clays of Aberdeenshire and Banffshire.

Of the vast periods of the Tertiary we have left to us, either in the Highlands or Scandinavia, but few and insignificant relics in the form of stratified deposits. In our beautiful Western Isles and in Antrim the lava poured out in successive streams, during enormous periods of time, from the lofty volcanic cones of the earlier Tertiary epoch, has here and there buried patches of lake-mud, or river-gravel, or ancient soils. But everywhere, alike in the Highlands and in Scandinavia, we behold the most impressive evidences of the sub-aerial waste, and of the elevation that promoted this waste during the Tertiary epoch. Among such evidences we may reckon the circumstance that all traces of the vast deposits of the Secondary periods have been relentlessly stripped away from the country, except where buried deeply by gigantic earth-throes, or sealed up under massive lava-streams.

Down to post-glacial times Scotland, and what are now its outlying islands, remained united with Scandinavia. I need not remind you how, during the glacial period, they were the scene of a similar succession of events; while from their then far more elevated mountain-summits streams of glacier-ice flowed down and relieved the mantle of snow which enveloped them.

But at a very recent geological period, and indeed since the appearance of man in this part of our globe, the separation of the two areas, so long united, was brought about. In the district now constituting the North Sea, which separates the two countries, great faults, originating in the Tertiary epoch, appear to have let down wide tracts of the softer Secondary strata among the harder crystalline rock-masses. The numerous changes of level, of which we find such abundant evidence around the shores of this sea, facilitated the wearing away of the whole of these softer Secondary deposits, except the slight fringes that remain along the shores of Sutherland, Ross, and Cromarty, on the one hand, and the isolated patches forming Scania, Jutland, and the surrounding islands on the other. Little could the Vikings, as they sailed over this shallow sea, have imagined that their predecessors in these regions were able to roam on foot from Norroway to Suderey!

It is almost impossible to over-estimate the effects produced by the several denudations to which Scandinavia and the Scottish Highlands have been successively subjected. In that which occurred during the later Tertiary periods, almost every portion of the non-crystalline rocks that rose above the sea-level was either entirely removed or converted into level plains, which, covered with drift deposits, now form districts like Scania and Denmark. Where, as in the great central valley of Scotland, hard volcanic masses are associated with the softer sedimentary rocks, the former are left rising as picturesque crags, standing boldly up above the general level, while the latter are worn down and buried under drift. In the west of Scotland a chain of volcanic mountains, with summits towering to the height of from ten to fifteen thousand feet, have been reduced by this same denudation to basal-wrecks, the highest portions of which attain to but little more than 3,000 feet above the sea-level!

During the great elevation and denudation which marked the Neocomian period, thousands of feet of strata must have been removed over wide areas, as is proved by the wonderful overlap of the Cretaceous beds on all the older strata.

Of the enormous sub-aerial waste which went on in these Northern Alps during the Newer Palæozoic periods we have impressive evidence in the vast masses of the Old Red Sandstone and Carboniferous rocks—themselves only a series of fragments that have survived the later denudations—for these rocks are built up of the materials derived from our Northern Alps.

The Torridon Sandstone is the monument, and a very striking monument too, of another and still earlier period of enormous denudation. The thousands of feet of conglomerate and sandstone of which it is made up consist of the disintegrated crystals of granites and gneisses that have been swept away.

When we penetrate towards the axis of this eroded mountain-chain, the proofs

of the magnitude of these denudations become even more striking and impressive. Here we see, towering aloft, the ruined buttresses of vast rocky arches, that when complete must have risen miles above the present surface; there we find, lying side by side, rock-masses that could only have been brought together by displacements of tens of thousands of feet; yet so complete has been the planing down of the surface since, that it requires the most careful study even to detect the almost obliterated traces of these grand movements. The Alps and the Himalayas, during their elevation, have suffered enormous waste and denudation; but if the elevation were to cease and the waste to go on till these magnificent mountain-chains were reduced to masses of diminutive peaks, ranging from 2,000 to 8,000 feet in height, we should then have the counterpart of this stupendous ruin of the mountain-chain of the north.

The history of the series of successive movements to which the rock-masses of our Highlands have been subjected is one well worthy of the most attentive study. When the evidence bearing upon the subject is carefully sifted and weighed, we become convinced of the fact that many of these movements—including some on a prodigious scale—must have taken place during what we are commonly accustomed to regard as comparatively recent geological periods.

On the eastern coast of Sutherland, a mass of Secondary rocks, including several thousands of feet of Triassic, Rhætic, and Jurassic strata, has been let down by a gigantic fault, so as to be placed in juxtaposition with the Old Red Sandstone and the crystalline rocks. Now, taking the very lowest estimates of the thicknesses of the several strata affected, the vertical 'throw' of this fault must have exceeded a mile! It may not improbably, indeed, have been at least double or treble that amount! Yet this great dislocation was certainly produced at a later date than the Upper-Jurassic period, for rocks of that age are found to be affected by it.

Along the coasts of the Black Isle, strata of Middle and Upper Jurassic age are similarly found faulted against the 'Old Red' and the crystalline rocks.

On the other side of the North Sea, in Ando, one of the Lofoten Isles, a patch of Lower-Oolite strata, consisting of marine and estuarine strata, and including beds of coal like that of Brora, is found let down by gigantic faults into the very heart of the crystalline rocks of the district. In Scania, the whole of the Secondary rock-masses owe their preservation in the same way to a plexus of tremendous faults, by which they have been entangled among the harder rocks. These faults have affected not only the Jurassic strata, but even the very youngest members of the Cretaceous series.

Nor are we without evidence that some of the great faults are of post-Cretaceous age, in this country, for in the Western Highlands displacements of several thousands of feet have been detected, which affect not only the Upper Cretaceous, but also the Older Tertiary rocks.

The effects produced by these great dislocations, which have a generally parallel direction in our Highlands, from north-east to south-west, are of the most startling character. Great strips of Triassic and Old-Red-Sandstone strata, like those of Elgin, and Turriff, and Tomintoul, and of the line of the Caledonian Canal, are found let down among the crystalline rocks by these gigantic faults.

The great central valley of Scotland itself consists of masses of Newer Palæozoic strata, faulted down between the harder Archæan and Lower Palæozoic rocks which form the Highlands on the one hand, and the Borderland on the other.

The evidences of the existence of these great faults were collected by many of the older Scottish geologists, like Landale, Bald, Chalmers, Milne-Home, and Nicol; and the accurate mapping of the country by the officers of the Geological Survey has, on the whole, tended to confirm their results. With regard to the age of these great dislocations of Central Scotland, it can only be *certainly* affirmed that they are of more recent date than the youngest Carboniferous strata; but I have long believed that, like many similar dislocations both in our own Highlands and in Scandinavia, they are really post-Cretaceous.

Less difficulty perhaps will be found in accepting this apparently startling

conclusion, when we remember that a complicated series of fractures injected by the lavas of the Great Tertiary volcanic foci of the West, extend right across the Highlands, the central valley, and the Borderlands of Scotland, and even traverse the whole series of the Secondary rocks in the North of England.

The indications of the tremendous manifestations of subterranean energy, to which these great dislocations owe their origin, are sometimes of a very striking kind. For hundreds of yards on either side of the faults, the two sets of strata are found bent and crumpled, and not unfrequently crushed into the finest dust ('fault-rock'). In the case of the great Sutherland-fault, to which I have previously alluded, we have a beautiful illustration of the way in which mineral veins may originate along such lines of fissure, for in the interstices of the granite of the Ord, where it has been broken up along this certainly post-Jurassic, and probably Tertiary fault, fluor-spar and pyrites have been deposited in large quantities.

It is impossible to study the tremendous movements and dislocations, and the enormous amount of denudation which have taken place in the Highlands and surrounding districts during Tertiary times, without being convinced that all the existing surface-features of the country must date from a comparatively recent period. The vast movements which have placed soft and hard masses in opposition along certain parallel lines—generally ranging in a north-east and south-west direction—and the denudation which has worn away the former, while it has left the latter standing in relief, must, I believe, both be referred to the Tertiary period; though the disposition of rock-masses brought about by earlier movements would of course exercise a certain though subordinate influence in producing the existing forms of the surface of the country.

At the close of the Jurassic period, and before the commencement of the Cretaceous, during the vast epoch marked by the deposition of the Neocomian of Southern Europe, a series of disturbances similar to those of the Tertiary, and scarcely inferior in their consequences, can be shown to have taken place.

If the movements of the Scandinavian and Scottish rock-masses, which took place in the Tertiary and Mesozoic periods respectively, were so startling in their magnitude and so vast in their effects, what shall we say concerning those far greater disturbances which affected the same area towards the close of the Older Palæozoic, and the beginning of the Newer Palæozoic, when this Northern Alps was still a living and growing mountain-chain?

These movements, in which both the Archæan and the Older-Palæozoic rocks are found to be involved, have resulted in the production, through enormous lateral pressure, of those reversed faults, caused by the disruption along their axial planes of greatly inclined and compressed folds as so well described by Rogers.

Dr. Archibald Geikie assures us that the studies of the geological surveyors in North-west Sutherland lead to the conclusion that certain masses of rock have thus been carried almost horizontally over others, along these 'thrust-planes' for a distance of at least ten miles. As the result of these tremendous lateral compressions, thin beds of limestone and quartzite, which have sufficiently definite characters to permit of their recognition, may be seen in Assynt, and in other parts of the Western Highlands, to be so repeated again and again by crumpling and faulting, that they have been regarded as deposits of enormous thickness; while, on the other hand, massive formations have been crushed and rolled out, thereby acquiring a laminated structure like so much pie-crust. Great portions of rock-masses, which, like the much-discussed 'Logan-rock,' have been nipped between gigantic faults, show evidence under the microscope of having been crushed to powder and subsequently reconsolidated, while the surfaces of the 'thrust-planes' sometimes exhibit the phenomena known as 'slickensides' on the most gigantic scale.

As we pass away from the central axis of this old mountain-chain, however, these complicated puckerings and dislocations pass gradually into more ordinary folds and faults, just as is the case with the Appalachians. The oft-repeated undulations of the Lower Palæozoic strata of the Borderland, so admirably described by Professor Lapworth, bear the same relation to the far more involved disturbances of rocks of the same age in the Highlands, which the foldings of the

strata in the Jura do to the intense crumplings of those of the Alps; and these in turn pass insensibly into the slightly undulating or horizontal strata of the southern half of this island.

We may perhaps add another comparison between the existing mountain-chain of Southern Europe and the 'basal wreck' of Northern Europe, one which I find has been already suggested by Professor Bonney. The Miocene Conglomerates, which in the Rigi and other flanking mountain masses of the Alpine chain are found piled to the depth of many thousands of feet, seem to be exactly represented in its prototype by the vast masses of the 'Old-Red' Conglomerate.

Vast as were the three series of movements to which I have been referring, I believe that the Scandinavian and Highland rocks bear the impress of a still grander series of disturbances than either of these—one at the same time of older date and far more universal in its effects.

Many writers have treated of the great divisional planes, almost everywhere conspicuous in the Highland rock-masses, as being necessarily coincident with planes of sedimentation. It is manifest, indeed, that the tracing of sequences and unconformities among such rocks must proceed upon the assumption that the planes of foliation and stratification *are* coincident. Murchison and Geikie so fully recognised the fact that this proposition lay at the very root of their arguments concerning a Highland succession, that they added a supplement to their paper to illustrate and enforce it.

It must not be forgotten, however, that the truth of this proposition has not only been doubted, but has been stoutly contested by many of the most profound thinkers on geological questions.

As long ago as 1822, Professor Henslow, in a very remarkable paper, showed that the rocks of Anglesea are traversed by a system of divisional planes, which intersect the bedding at a very high angle, and must have been produced long subsequently to the latter; and in 1835 Professor Sedgwick extended the observations and enforced the arguments of Henslow.

At an even earlier date, Poulett Scrope had shown, by his study of viscous lavas, that the planes along which crystalline action takes place are determined by pressure and strain; and he insisted that the foliation of metamorphic masses was a phenomenon strictly analogous to the banding of rhyolitic lavas.

Charles Darwin, the pupil of Henslow and the friend of Poulett Scrope—whose labours in the geological field would perhaps have met with fuller recognition had they not been overshadowed by his still greater achievements in the world of biological thought—strongly maintained the truth of these views. He added the important observation that, in the South-American continent, the planes of foliation are seen everywhere, over enormous areas, to be parallel to those of cleavage; and that these latter are of secondary origin and due to lateral pressure, the observations of Sharpe and the experiments of Sorby have convincingly demonstrated.

That the schists and gneisses of our Highlands and of Scandinavia have resulted from crystallising forces, acting upon strata of sandstone, clay and limestone, or upon igneous materials constituting lava-currents, or intrusive sheets, dykes, and bosses, I see every reason for believing. That these re-crystallised and highly-foliated masses in the great majority of cases maintain their original positions and relations, or indeed anything approaching their original positions and relations, I greatly doubt; and my doubt on this point has increased the more I have studied the Highland rocks.

Thin bands of quartzite may be the rolled-out representatives of massive beds of sandstone or conglomerate; wide-spreading schists may consist of the crystallised materials of clays and shales, crumpled, pleated, and kneaded together in endless convolutions; vast sheets of gneiss may have originally been intrusive bosses of granite or thick strata of arkose. How, then, are we to apply the ordinary principles that regulate questions concerning dip and strike, and unconformity in the case of sedimentary deposits, to highly-altered rocks like these?

The observations of Jukes, Allport, and Phillips on some of the simpler and more easily explicable examples of the production of foliation in rocks require to be cautiously extended, by patient study in the field and in the laboratory, to cases of

a more complex and difficult character. Especially in this connection do we welcome such contributions to our knowledge as that made by Mr. Teall in his description of the remarkable foliated dyke of Scourie.

Very significant indeed is the fact that the phenomenon of foliation appears to be confined to regions which have been the scene of the most violent subterranean movement and disturbance. That solid rock-masses, subjected to the tremendous earth-strains to which they are liable during mountain-making, are capable of internal movement and flow—like the ice of a glacier—we have the clearest evidence. Many illustrations might be adduced in support of the view that crystallisation is influenced and controlled by mechanical forces—pressures, stresses, and strains. May it not also be true, as long ago suggested by Vose, that the heat which must be generated in the great shearing movements taking place in rocks have also had much to do in giving rise to that re-crystallisation which is the essence of foliation? Rock-masses, in the throes of mountain-birth, have, like glaciers, behaved substantially as viscous bodies; may not the former have undergone molecular changes analogous to regelation in the latter?

That many of the stupendous earth-movements which produced the foliation of the rocks of Scandinavia and the Scottish Highlands must be referred to Archæan times, there is not the smallest room for doubt. That similar effects have resulted from the same agencies during subsequent periods, our fellow-geologists in Scandinavia believe they have found incontrovertible proof. For my own part I look forward confidently to the establishment of the same conclusion from the study of our own Highland rocks.

But here I am conscious that I am venturing on topics upon which great and allowable differences of opinion still exist. The debates in this Geological Section during the first meeting of the British Association in Aberdeen ought, I think, to have marked the practical close of one great series of controversies. The discussions of the present meeting will, I trust, result in the recognition and clear statement of a number of other equally important problems of Highland geology which still await solution. And I am sanguine enough to hope that when this Association next gathers here, my successor in this chair will have to congratulate his audience upon a very brilliant retrospect of work actually accomplished in the interval.

I am encouraged in this optimism by the fact that in the period which has elapsed since our last meeting here, great and important improvements have been made in the methods of geological investigation. We have seen how the discovery of a few fragmentary shells in the limestone of Durness, and of sundry casts of bones in the sandstone of Elgin, have been the means of profoundly modifying our ideas concerning the age of vast tracts of rock in the Highlands. The development of modern methods of petrographical research is destined, I believe, to lead to a similar revolutionizing of our views concerning the wonderful series of changes which have taken place within rock-masses, subsequently to their original accumulation.

Especially does the application of the microscope to the study of rocks, when employed in due subordination to, and illustration of, work done in the field, promise to be the source of valuable and fruitful discoveries in the field of Highland geology.

In connection with this subject, I cannot refrain from reminding you that while the initiative in the application of the palæontological method of research was taken by an English land-surveyor, we are indebted to a Scotchman in an equally lowly station of life, for overcoming some of the first difficulties in connection with petrographical study. Many microscopists had employed their instruments, and sometimes with useful results, in the study of the powders and the polished surfaces of rocks; but it is to William Nicol of Edinburgh, the inventor of the well-known polarising prism which bears his name, that we owe the discovery of the method of preparing transparent sections of fossils, crystals, and rocks, whereby their internal structure may be examined by transmitted light. Nicol bequeathed his preparations to his friend Alexander Bryson, and some of them are now preserved in the British Museum. It is interesting, too, to recall the circumstance that it was a thin section of the granite of Aberdeen in the collection of Bryson which exhibited to

Sorby that wondrous assemblage of minute cavities containing liquids, and led him, shortly before our previous meeting here, to write his paper 'On the Microscopical study of Crystals, indicating the origin of Minerals and Rocks'—a paper which has indeed proved epoch-making in the history of geology.

Before concluding the remarks which by your kindness I have been permitted to offer you to-day, I cannot forbear from indulging in a pleasant reminiscence of a personal character. Nearly fifteen years have passed away since I first visited the Highlands for the purpose of geological study; it was at that time I first found myself at liberty to put into practice a scheme cherished by me from boyhood, that of studying those Secondary rocks and fossils of the Highlands, among which such valuable pioneer work had been done by John Macculloch, Roderick Murchison, and Hugh Miller. I had endeavoured to prepare myself for a somewhat difficult task, by a training partly unofficial and partly official—I will not employ the terms 'amateur' and 'professional,' for of late they have been so sadly misused—but when I came a stranger among you, I could not have deserved, and I certainly did not anticipate, that cordial welcome, that kindly aid and that generous appreciation, of which I accept my position here to-day as the crowning manifestation.

While I continue to occupy myself with the glorious problems of Highland geology—and hitherto I have found that each difficulty surmounted has resulted, like the sown teeth of the slaughtered dragon, in a plentiful crop of new ones—the many acts of kindness of my numerous friends here can never cease to be present in my mind. For not only am I indebted to those who, like your own Dr. Gordon of Birnie and Dr. Joass of Golspie, have been able out of the stores of their knowledge to furnish me with 'things new and old,' and who have been unfailing in their aid and sympathy, but to those also who have pitied, but nevertheless helped, the 'daft callant that speers after the chucky stanes.'

I know of no higher pleasure than that which the geologist experiences in visiting regions of great scientific interest which are new to him, and of grasping the hands of fellow-workers, whose labours and teachings he has learned to admire and to appreciate. Whatever may be my lot in this way in future years, however rich the country visited may be in objects of profound instructiveness or of surpassing interest, I can anticipate or desire nothing more valuable than the lessons, or kinder than the reception which I have met with here.

'I'll ask na mair, when I get there,
Than just a *Hielan* welcome.'

The following Reports and Papers were read:—

1. *Report on the Volcanic Phenomena of Vesuvius.*—See Reports, p. 395.

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2. *Fifth Report on the Earthquake Phenomena of Japan.*
See Reports, p. 362.

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3. *On some recent Earthquakes on the Durham Coast, and their probable cause. By* Professor G. A. Lebour, *M.A., F.G.S.*

Since the end of 1883 up to the present time the inhabitants of certain portions of the town of Sunderland have been much disturbed by a series of small but distinctly sensible earthquakes, which have caused considerable discussion in the local press and elsewhere. These shocks were chiefly felt in that quarter of the town known as the Tunstall Road, but were not absolutely limited to that locality. They were accompanied by rumblings—sometimes dull but often loud—by the rattling of crockery and furniture, and frequently by very distinct shakes of the entire framework of buildings. Often the shocks have, at night, waked up and terrified the sleeping inhabitants.

The probable origin of these disturbances has naturally been much canvassed, and blasting in quarries, shot-firing in collieries, and the passing of railway trains have in turn been accused of causing them, and, on examination, have been found 'not guilty.' At the present time there is no doubt whatever that the shocks are due to some *natural* cause. As to what that natural cause may be there is, perhaps, room for difference of opinion.

My friend Mr. M. Walton Brown, of the Coal Trade Offices at Newcastle-upon-Tyne, in a paper read in 1884 before the North of England Institute of Mining and Mechanical Engineers, refers to the Sunderland shocks as being genuine earth-tremors, but I think that their extremely local character—setting aside many other points inconsistent with this view of their origin—is conclusive against this being so.

In another paper, read, at the same time as Mr. Walton Brown's, before the same Institute, I brought forward a number of facts tending to connect the phenomena above referred to with certain peculiarities in the geological structure of the district. Since that time, the shocks having continued more or less continuously, and evidence of all kinds with regard to them having accumulated, I wish to lay my more mature views on the subject before Section C, in the hope that members in discussing them may help to elicit the truth.

Sunderland stands upon the Permian Magnesian Limestone, of which there is from 300 to 400 feet beneath the town. This rock is riddled with cavities of every size and shape. The smaller ones give a vesicular aspect to the stone in many places, but the larger ones are often true caverns, due to the combined action of mechanical and chemical agencies. Many of them may be accounted for by noting how frequently masses, both large and small, and of all shapes of soft pulverulent matter occur in the midst of the most compact and hard portions of the limestone. How easily such soft, incoherent, earthy rock, or 'marl,' as it is called locally, can be removed by the merest percolation of rain-water where there is an outlet needs no proof, and that caverns would result and have resulted from such removal is clear. This action is indeed chiefly mechanical, but there is also going on at the same time a very considerable destruction or removal of rock by the ordinary chemical action of rain-water on limestone. I have shown elsewhere that every thousand gallons of Sunderland water, pumped up and ultimately thrown into the sea, represents one pound of stone abstracted. In each year the Water Company robs the Magnesian Limestone in this manner of about forty cubic yards of rock, and, of course, much more is carried off annually by natural channels. How large some of the cavities are which form water-cisterns in this rock may be gathered from the fact that when, in sinking a shaft at Whitburn Colliery in 1874, one of them was unfortunately tapped, it yielded 11,612 gallons of water per minute for a month.

The rock then immediately underlying Sunderland is a mass of calcareous stone mostly hard and compact, but cellular in places and earthy and friable in others, often cavernous on a large scale, full of water, and through its action continually parting with its substance, and *thus enlarging the cavities within it.*

Under conditions such as these, it follows necessarily that the vaults of cavities must, from time to time, give way, and, in collapsing, produce concussions accompanied by noise, but limited in the area over which their effects would be felt. In short, it seems to me that we have in such natural stone-falls at moderate depths a sufficient explanation of the Sunderland earth-shocks.

In the paper before alluded to I pointed out that this theory explains equally well all the facts connected with the singular fissures full of breccia ('breccia-gashes'), which are common in the Magnesian Limestone of Durham, and have been a standing puzzle hitherto to Lyell, Sedgwick, and all the geologists who have published accounts of the magnificent sections exhibited along the coast between South Shields and Sunderland.

Quite recently very similar shocks have been felt, as I am informed, in the neighbourhood of Middlesborough, where it is probable that they are due to the withdrawal of rock-salt, which has been going on there of late years only. In this case the depth at which the cavities are being formed and rock-collapses are, as I

believe, taking place is much greater than in the Sunderland case, the borings for salt being from 1000 to 1200 feet deep.

I will conclude with a quotation from my paper on the Breccia-Gashes [1] (p. 174): 'The forms of these gashes, which are gullet-shaped and tapering downwards, unlike the sea-caves; the breccia with which they are filled, the matter with which the fragments are cemented, the half-broken beds which so often bridge over the upper portions of the fissures, and the unbroken beds immediately above and below them, which would be inconceivable had the fissures and their infillings been due to real earthquakes—all these things are necessary accompaniments of the rock-collapses which, it has been shown, must in time past have happened frequently, are happening still, and must happen more and more frequently in the future.'

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4. *Notice of an Outline Geological Map of Lower Egypt, Arabia Petræa, and Palestine. By* Professor EDWARD HULL, *LL.D., F.R.S., F.G.S.*

The map exhibited was enlarged from that which accompanies the author's book 'Mount Seir, Sinai, and Western Palestine,' giving a narrative of the expedition sent out into these countries by the Palestine Exploration Society in 1883–84. It embraces a region extending from the valley of the Nile on the west to the table-land of Edom (Mount Seir) and Moab, including the Jordan-Arabah Valley, and the mountains of Sinai. Its northern limit is the Lebanon. The following formations and divisions are represented:—

RECENT.	1. Sandhills of Lower Egypt, the coast of Palestine, and Arabah Valley. 2. Alluvial Deposits of the Nile, the Ghor, and Jordan Valley. 3. Gravel of the Wâdy el Arabah.
RECENT AND POST-PLIOCENE TO PLIOCENE.	1. Raised Beaches bordering the Gulfs of Suez and Akabah, the Isthmus of Suez, and borders of Palestine. 2. Ancient Deposits of the Salt Sea (Dead Sea). 3. Old Lake-beds of the Sinaitic Peninsula and Arabah Valley.
EOCENE TO CRETACEOUS.	1. *Upper Eocene.* Calcareous Sandstone of Phillistia. 2. *Middle and Lower Eocene.* Nummulite Limestone. 3. *Upper Cretaceous.* Cretaceous Limestone. 4. *Cenomanian.* Nubian Sandstone.
LOWER CARBONIFEROUS.	1. Limestone of Wâdy Nasb. 2. Desert Sandstone and Conglomerate.
METAMORPHIC ROCKS. (Archæan ?)	Granite, Gneiss, and various kinds of Schist.
MODERN VOLCANIC ROCKS.	Basalt, Dolerite, &c.
ANCIENT VOLCANIC OR PLUTONIC ROCKS.	Granite, Porphyry, Felstone, Diorite, &c. Beds of Tuff and Agglomerate of Wâdy Haroun and Jebel esh Shomrah.

The main lines of fault and dip of the strata are also indicated.

As an outline of the scientific results which were arrived at by the members of the expedition, and which are represented on the map, had already been communicated to the Association,[2] it was not considered necessary to repeat them here, but the author wished to add that a topographical and geological map of the Arabah

[1] See *Trans. N. E. Inst. Min. Eng.* vol. xxxii. (1884)
[2] *Rep. Brit. Assoc.* (Montreal Meeting, 1884), Transactions of Sections C and E.

Valley on a scale of about six miles to one inch was in preparation, and would accompany the Geological Memoir now in the press for the Palestine Exploration Society. The topographical survey had been made by Major Kitchener, R.E., and Mr. John Armstrong (formerly sergeant-major, R.E.), and the geological details had been inserted by the author. In addition to these, several longitudinal geological sections, illustrating the structure of various parts of this region, and numerous drawings would accompany the Memoir.

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5. *On the Occurrence of Lower Old Red Conglomerate in the Promontory of the Fanad, North Donegal. By* Professor EDWARD HULL, *LL.D., F.R.S., F.G.S.*

The district in which the Old Red Conglomerate occurs is formed of ridges and valleys of metamorphic rocks, consisting of beds of quartzite, schist, crystalline limestone, and trap, chiefly diorite. It lies between Lough Swilly and Mulroy Bay, and is washed on the north by the waters of the Atlantic. The remarkable tract of the Old Red Conglomerate, recently discovered by the officers of the Geological Survey, is far remote from any mass of the same formation, and it is unrepresented on any geological map hitherto published.

The beds consist of red and purple sandstone and conglomerate, made up chiefly of quartzite pebbles and blocks, but also containing others of limestone and trap; all derived from the surrounding metamorphic series. They occupy an area of over two miles in length and half a mile across, extending along the northern base of Knock Alla, a ridge of quartzite which traverses the promontory from side to side. The beds dip towards the base of the mountain, against which they are let down by a large fault, and they terminate along their northern edge by an unconformable superposition on beds of quartzite and limestone. They reach a total thickness of about 800 feet.

From the position of these beds it becomes evident that they are unconnected with any of the recognised basins of Lower Old Red Sandstone, either in Scotland or Ireland, and may, therefore, be regarded as having been formed in an isolated basin. The tract will be a new feature on geological maps of Ireland.

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6. *On Bastite-Serpentine and Troktolite in Aberdeenshire; with a Note on the Rock of the Black Dog. By* Professor T. G. BONNEY, *D.Sc., LL.D., F.R.S., Pres. G. S.*[1]

Bastite-serpentine (as noticed some time since by Professor Heddle) occurs near Belhelvie and on the shore near the Black Dog. The author describes the microscopic structure of this, showing that it consists of olivine and its alteration products, enstatite in various stages of alteration, and a mineral of the spinellid group. Associated with this in the Belhelvie district is a fairly normal troktolite, consisting of a plagioclastic felspar allied to anorthite, olivine, more or less altered, and a little diallage. It closely resembles the typical Volpersdorf rock, but has rather less magnesia and more alumina, corresponding chemically more nearly with a rock described by the author from Coverack Cove, Cornwall. He is of opinion that the two rocks differ somewhat in age, though probably the earlier was still at a high temperature when the later was intruded, and he inclines to the view that the serpentine is the older rock of the two.

The Black Dog has been incorrectly described as consisting of 'crystals of *talc* matted in such confusion as to form both a tough and hard rock.' The rock really consists of quartz, sillimanite, two kinds of mica, an iron oxide (hematite?), and most probably some dichroite, with perhaps a little kyanite. In short, the rock presents a very close resemblance under the microscope to some specimens of the well-known 'cordierite gneiss' of Bodenmais.

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[1] Published in full in the *Geological Magazine*. 1885, p. 439.

7. *On certain Diatomaceous Deposits (Diatomite) from the Peat of Aberdeenshire.* *By* W. Ivison Macadam, *F.C.S., F.I.C.*

The material was found below the peat in certain districts of Aberdeenshire, but principally in the basin in which lie Loch Kinnord and Davin. After removal of the surface peat fuel the lower and more highly mineral portion was cut in blocks and air dried. The substance then consisted of almost pure diatomacea bound together by the remains of sphagnum, equisetacea, &c. Besides being found underlying peat, the substance was also obtained on the shores of Loch Kinnord, and the more pure diatoms were thickly distributed over the bottom of the deeper portions of the lake. These latter, however, from the want of the binding obtained from the marsh plants above stated, could not be rendered readily available for market. An interesting point regarding these deposits was, that, whilst in Loch Kinnord an abundant supply of the diatoms could be obtained, in the neighbouring Loch Davin scarcely a single diatom (recent or fossil) was found. This was probably due to the fact that, whilst the feeding waters of Loch Kinnord flowed from hills consisting of a coarse and much disintegrated granite, and consequently containing a considerable proportion of soluble silica, the Loch Davin waters were obtained from hornblendic mountains, and held much less soluble silica in solution.

The material was principally used for the manufacture of dynamite, and a considerable quantity had been forwarded to the works for this purpose. Other uses could be found for the material, such as the manufacture of ultramarine, for which from the very small proportion of iron present the diatomite was more especially to be recommended. As an absorbent, it was of fully double the value of the ordinary German varieties of Kieselgpohr.

The paper was illustrated by specimens and diagrams.[1]

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8. *List of Works on the Geology, Mineralogy, and Palæontology of Staffordshire, Worcestershire, and Warwickshire.* *By* W. Whitaker, *B.A., F.G.S., Assoc.Inst.C.E.*—See Reports, p. 780.

FRIDAY, SEPTEMBER 11.

The following Papers and Reports were read :—

1. *The Volcanoes of Auvergne.* *By* Tempest Anderson, *M.D., B.Sc.*

The modern dry plate process of photography has placed in the hands of geologists the power of rapidly and faithfully recording and reproducing before an audience of any size many geological and especially volcanic phenomena which it would be impossible adequately to describe in words.

By means of the oxyhydrogen lantern a number of photographs were shown on the screen which had been taken by the author in the volcanic district of the Auvergne and adjacent parts of the Velay and Vivarais, in Central France.

Cones of scoriæ with craters were contrasted with the Domitic Puys in Auvergne, and these again with the Phonolitic hills in the district of the Mezenc. The appearances of various lava streams both on the surface and where exposed in sections were shown, especially those of the valleys of Jaujac and Montpezat. Lakes in extinct craters were contrasted with those formed in pre-existing valleys behind dams of volcanic ejecta, and the general scenery of volcanic rocks was compared with that of other adjacent formations.

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[1] *Trans. Edin. Geo. Soc.*, vol. iv.; *Trans. Min. Soc. of Great Britain*, 1884; *Chemical News*, November 21, 1885.

2. *On the Re-discovery of lost Numidian Marbles in Algeria and Tunis. By* Lieut.-Colonel R. L. Playfair.

The author explained that the name itself was a misnomer, as they are not found within the limits of Numidia proper, but in the province of Africa and in Mauritania. Most of the 'Giallo antico' used in Rome was obtained from *Simittu Colonia*, the modern Chemtou, in the valley of the Medjerda, the quarries of which are now being extensively worked by a Belgian company; but the most remarkable and valuable marbles are found near Kleber, in the province of Oran, in Algeria. There, on the top of the Montagne Grise, exists an elevated plateau, 1,500 acres in extent, forming an uninterrupted mass of the most splendid marbles and breccias which the world contains. Their variety is as extraordinary as their beauty. There is creamy white, like ivory; rose colour, like coral; Giallo antico; some are as variegated as a peacock's plumage; and on the west side of the mountain, where there has been a great earth-movement, the rock has been broken up and re-cemented together, forming a variety of breccias of the most extraordinary richness and beauty.

Colonel Playfair exhibited specimens of the principal varieties, to prove that his descriptions were not exaggerated. The beauty of these marbles has been recognised by the trustees of the British Museum, who are now mounting the sculptures of the Parthenon and the Mausoleum on basements of them. Specimens may also be seen in the Mineralogical Room of the British Museum, at South Kensington.

The marble mountain belongs to Signor del Monte, of Oran, and, although it is not being worked as it ought to be, blocks can be obtained at a cost of about 18*l.* per cubic mètre, ready for shipment.

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3. *Second Report on the Rate of Erosion of the Sea Coasts of England and Wales.*—See Reports, p. 404.

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4. *The Chasm called the Black Rock of Kiltearn. By* William Watson.

This is a narrow ravine in conglomerate: its length is about $1\frac{1}{4}$ mile; its depth varies from 100 to 130 feet; its breadth at the top varies from 12 or 15 to about 30 feet. The river which flows through the ravine is the Altl-Gránda; it drains Glen Glass (above the ravine); the water flows into Cromarty Firth.

The author refers to popular views held to explain the formation of the ravine —earthquakes and fracture, and shows that these are inadequate. The ravine has clearly been produced by erosion, of which the marks are still visible on the sides; the difficulty is to explain how erosion could have produced a gorge of this kind without weathering action and floods having denuded the sides.

Above the gorge in Glen Glass was once a lake. This had been silted up to the height of about 80 feet with sand, washed out of the Glacial *débris* of the glen. When the barrier that confined the lake gave way the river flowed over the surface of the conglomerate, carrying with it much sand from the lake-silt, and using this as a means of rapidly eroding the rock. When the chasm was deep enough to prevent the floods from overflowing the banks the sides could not be widened to any great extent. The disproportion between the deepening and widening process has been maintained, thus causing the steep-sided narrow glen. The excavation now going on is small, whilst the weather has some effect on the sides; so that ultimately an ordinary valley will be produced.

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5. *The Bass of Inverurie, a fragment of an ancient Alluvial Bed. By the* Rev. John Davidson, *D.D.*

The Bass of Inverurie, a green conical hill about 50 feet high and singularly symmetrical, stands isolated in a corner of the united river valleys of the Don and Ury, which latter stream washes its base.

Its form and position were until lately accepted as proving it to be of artificial origin, and speculation dealt only with hypotheses of the reason of its being erected. Some of these, being of a superstitious character, increased the unwillingness to have the mound dug into which veneration for its antiquity and its traditional history occasioned. The character of the great mound was discovered by accident in 1883, when a burying ground was being prepared around its base.

The Bass has a prolongation half the height called the Little Bass. In laying out the graveyard a walk was made round the conical portion, so as to complete the outline of the cone. A way had to be excavated between the Bass and Little Bass. The work showed for a day or two a vertical section, which, being observed, was examined by a geological expert and pronounced to be clear evidence that the hill was produced by successive deposits of sand laid down in the valleys of the Don and Ury, until a sand bed lay there whose surface was of the height of the top of the Bass. Upon that level, 40 feet higher than the present level of the Don and Ury, these streams flowed before the Bass began to be formed; and in course of time it was gradually formed by denudation, something accidentally protecting a spot of surface while the streams washed away the soil around. The river beds were gradually deepened, while the Bass, once begun to stand up out of the flood, got broader and broader, turning the two converging streams aside.

The alluvial origin of the Bass infers the existence of a breadth of flowing water over the whole range covered by the sand bed, which can be traced five miles back from the Bass in the line of both rivers. The existence of that lake infers the existence of others between it and the sea. Ordnance levels and existing rocky narrows in the line of the Don point out the outlines of those lakes.

The continuing preservation of the form of the Bass, notwithstanding that the Ury impinges upon it at right angles, is due to the circumstances that a bed of boulder clay 30 feet wide underlies the Ury and the centre of the Bass. The boulder clay was discovered in building a wall for the graveyard, and the bed has since been found a mile south in digging a well at the Inverurie paper mills. It is there 46 feet thick.

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6. *Thirteenth Report on the Erratic Blocks of England, Wales, and Ireland.* See Reports, p. 322.

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7. *The Direction of Glaciation as ascertained by the Form of the Striæ. By* Professor H. Carvill Lewis.

As there seemed to be a disagreement between certain Scotch geologists and the Irish geologists regarding the inferences as to the direction of glaciation to be deduced from the form of glacial striæ, the author was led to bring forward some observations of his own, made in America and in Great Britain, which threw light upon the disputed point.

Well-preserved striæ are frequently blunt at one end and tapering at the other, the shorter ones sometimes resembling the characters used in the cuneiform inscriptions. This form may be seen in striæ of all sizes—from those several yards in length, when the blunt end may be an inch or more in breadth, to the finest scratches, where a microscope is necessary to detect any difference between the two ends.

As shown in the Reports of the Boulder Committee of the Royal Society of Edinburgh[1] and elsewhere, certain Scotch geologists regard the blunt end as the point of impact of the striating agent, and as therefore pointing to the direction from which the motion came. On the other hand, the Irish geologists[2] interpret the shape of the striæ as indicating motion in the opposite direction, believing the tapering end to point to the direction from which glaciation proceeded. The point

[1] Fifth Report, pp. 18–20, 29, 58; and Seventh Report, p. 18.

[2] *Memoirs Geolog. Surv. of Ireland.* Explanation to sheets 86, 87, 88, p. 55 Explanation to sheet 193, p. 18, &c.

at issue is of importance, especially in outlying islands and elsewhere, where other indications of the direction of glaciation fail.

In Pennsylvania, which is crossed from east to west by the terminal moraine of the great ice-sheet, and where the glaciation is uniformly in a southward direction, the author had observed that the blunt ends of the striæ, where flat surfaces were studied, were always to the south.[1] In certain instances the mode of formation of the striæ was also indicated by their shapes, which showed that a stone pushed along under the glacier had ground in deeper and deeper until, in some cases, it stopped or hopped out, in other cases was ground down to another cutting edge, and in others *turned over* and began its work of engraving by a fresh and sharp corner. The peculiar gouges at the farther end of certain striæ showed a sort of slow rocking motion in some stones before they finally turned over.

The author's observations in Ireland, both at localities where there could be no doubt as to the direction of glacial movement, and at localities where such direction was not previously known, led to conclusions entirely in harmony with those already reached in Pennsylvania and with those held by the Irish geologists.

One of the best examples falling under the former category was among the local glaciers in the mountains of the Dingle promontory, a region not invaded by the great confluent ice-sheet of Central Ireland. The striated beds of these small glaciers, beginning in a 'corry' and bounded below by a semicircular terminal moraine, are beautifully defined and afford good opportunities for striæ study. It was found that *the wedge-shaped striæ are blunt at the advancing end except on convex downward surfaces, where the reverse is the case.* While this rule does not hold good for every individual scratch at a given locality, it has been found most useful when applied to striated surfaces in general.

At Glengariff, where some finely striated surfaces occur, a number of tracings were taken directly from the rock, which clearly show the broader ends of most of the striæ to be to the south, the direction toward which the glacial stream advanced. Similar observations were made at several localities south of the Shannon.

Finally, as an instance where the direction of glaciation was previously unknown, certain striæ were described which the author had observed on the top of the cliffs facing the Atlantic at Kilkee. These point N. 58° W. and S. 58° E., and the question to be determined was whether the glaciation proceeded from the Atlantic towards the land, or whether it went north-westward and out to sea. The form of the striæ alone decided it. Their broad blunt ends were, as a rule, toward the N.W.—the surface being horizontal—a fact which, taken in connection with other observations made about the mouth of the Shannon, showed that a great ice stream had flowed westward along the valley of the Shannon, and had opened out fan-shaped as it plunged into the sea.

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8. *Proposed Conditions to account for a former Glacial Period in Great Britain, existing under similar meteorological conditions to those that rule at the present time. By* W. F. Stanley, *F.G.S., F.R.M.S.*

This paper may be considered as a continuation of a paper read by the author last year, in which it was argued that climates did not appear to be greatly influenced by excentricity of the earth's orbit or the position of winter perihelion, as assumed by Dr. Croll and other physicists of the present time. The southern hemisphere, assumed to be the colder, was shown by observation to be the warmer. Therefore, looking to other causes for former glaciation, the author suggested that these were possibly local phenomena which were dependent upon geographical conditions. The former glaciation in Great Britain and Western Europe was supposed by the author to be due to the following conditions:—

1. The non-existence of the Isthmus of Panama, by which the warm southern tropical current, now deflected by Cape St. Roque, in South America, into the

[1] On the Terminal Moraine in Pennsylvania and Western New York. Report Z. *Second Geolog. Survey of Penn.*, pp. 33, 85, 86, 107, 275.

Northern Atlantic, formerly flowed into the Pacific Ocean, leaving the entire Northern Atlantic at its mean normal latitude temperature in comparison with other oceans.

2. A former depression of North America in W. long. 80° to 90°, by which the northern tropical current, now deflected by resistance of land through the Straits of Florida, formerly flowed where we have at present the Mississippi valley, the great American lakes, and Hudson's Bay, by which cause warm currents bathed the western coast of Greenland, and, turning to the north of this continent, produced a compensating return current from the Arctic regions which flowed southward along Western Europe and Great Britain, bringing with it icebergs, as at present the compensating current to the Gulf Stream brings icebergs to the coast of Labrador.

3. Higher elevation of some interior part of Great Britain of the older strata now denuded, by which, at the temperature then ruling, glaciers flowed from the interior.

For the general principles of oceanic circulation reference was made to the discussion of this subject, given by the author in his work on fluids.

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9. *On the Fynnon Beuno and Cae Gwyn Bone-Caves, North Wales.* *By* H. Hicks, *M.D., F.R.S., F.G.S.*

In the 'Proceedings of the Geolog. Assoc.' vol. ix. No. 1, I have given an account of the discovery of two bone-caves in the carboniferous rocks on the east side of the Vale of Clwyd, North Wales, and of the researches carried on in those caverns by Mr. Luxmoore, of St. Asaph, and myself, in the summers of 1883 and 1884. This summer, by the aid of a grant from the Royal Society (the Government grant), we were enabled to employ a staff of workmen, under our personal supervision, to explore these caverns more thoroughly, and with very satisfactory results. Our main object was to gain a clear idea of the physical conditions of the area when the caverns were filled with the deposits, and of the manner in which the remains had been conveyed into them. These points we think we have been able to prove to satisfaction, but it may be advisable to continue the researches for the purpose of obtaining as much confirmatory evidence as possible.

In the *Cae Gwyn Cavern* all the deposits were entirely undisturbed except by burrowing animals when we first discovered it, and great care was taken throughout to notice the conditions of the materials. The deposits in this cavern consisted of, first, a reddish clayey earth, varying in depth from two to four feet. Below this was found a more compact deposit consisting of thin layers of a fine marly clay, about 18 inches in thickness, and under this the material containing the bones This material consisted of a reddish clay, with sand in places, and contained many boulders similar to those found in the boulder clays of the district. Large fragments of a stalagmite floor and of stalactites occurred also in it, showing that the water action which disturbed the original materials in the cave must have been of a violent nature. Under this was found a gravelly deposit, containing fragments mainly from the hills above, and no bones. In this cavern the deposits, except the lowest, have been cleared out to a distance from the entrance of over 150 feet. This cavern is for the most part a true tunnel cavern with well smoothed roof and sides. The largest chamber has just been reached at a little over 150 feet from the entrance. It is over 11 feet in length and 9 feet in height. The other chambers are small, being mainly dilatations of the tunnel, which varies from 3 to 9 feet in width. Extending from a small chamber, about 45 feet from the entrance, there is another branch tunnel whichhas been explored to a distance of about 16 feet.

The bones discovered in this cavern, according to Mr. W. Davies, F.G.S., of the British Museum, to whom they have been submitted, belong to the lion, hyæna, bear, badger, wolf, fox, great Irish deer, reindeer, red deer, roebuck, rhinoceros, and horse. A flint scraper was also found last year in association with the remains at a distance of 45 feet from the entrance.

The *Fynnon Beuno Cavern* is partly a fissure and partly a tunnel cavern. From

the entrance inwards for a distance of about 40 feet it is a true tunnel cavern, and there is a branch tunnel extending from this for a further distance of over 50 feet, ultimately opening out on the hill side above the main entrance. Another tunnel communicates with an extensive fissure cavern, which had evidently been disturbed at some time by mining operations, though I could obtain no information as to when. In the undisturbed parts of this cavern the deposits were of a similar character to those in the Cae Gwyn Cave. This cavern, however, being for some extent an open cavern, had probably been inhabited in Neolithic, or perhaps later times, as a quantity of charcoal was found at two points at distances of from 20 to 24 feet from the entrance. Several well-worked flint flakes were found at different points in this cavern, in association with bones of the mammoth, rhinoceros, &c. Dr. Evans recognised them as of the type of the wrought flakes found in Kent's Cavern. They also, like those found in Kent's Cavern, are white and porcellanous, and all show indications of having been used, but not rolled by water action. Worked bones and others broken by man were also found. The bones, which were exceedingly plentiful in the cavern, were found to have been gnawed freely, and evidently when in a fresh condition, hence showing clearly that they had been conveyed into the cavern soon after the animals had died. Some *album græcum* was also found in each of the caverns, therefore the evidence points clearly to their having been dens occupied by the beasts of prey. I think we are quite justified also in supposing, from the positions of the flakes and worked bones, that the caverns were occupied by man, or at least that the district was inhabited by man when the mammoth, rhinoceros, reindeer, hyæna, &c., roamed about the area.

The bones found in this cavern belonged to the following animals, viz., lion, wild cat, hyæna, bear, wolf, fox, wild boar, great Irish deer, reindeer, red deer, roebuck, bos, mammoth, rhinoceros, and horse. The remains were much more plentiful in the Fynnon Beuno than in the Cae Gwyn Cave. Among the specimens found in the two, there were over 80 jaws belonging to various animals, and more than 1,300 loose teeth, including about 400 rhinoceros, 15 mammoth, 180 hyæna, and 500 horse teeth. Other bones and fragments of bones occurred also in very great abundance.

As these caverns are about 400 feet above present sea level, and nearly 300 feet above the river Clwyd (the height given in my paper to the Geologists' Association was understated), it is clear that great physical changes must have taken place in this area since the time that the marine sand was conveyed into these caverns. The broken stalagmite floor, sometimes 10 to 12 inches in thickness, and the broken stalactites 6 to 8 inches across, show that the water action must have been also of a violent nature. The position of the bones in some places under still adherent parts of this stalagmite, and the presence of marine sand in the hollow parts of the bones, show that the bones must have been in the caverns before the sea finally receded from them. The presence also of a material, in every respect like the boulder clay of the district filling up the caverns, points to the probability that the so-called Upper Boulder clays of this district were deposited for the most part at the time, or subsequent to the infilling of these caverns. Along the hill-sides in the ravine in which the caverns are situated, sands and clays similar to those found in the caverns, and containing marine shells, are found at about the same horizon and in the hills to the S.E. at much greater elevations. Cae Gwyn Cave is over 60 feet, and Fynnon Beuno 42 feet above the level of the little stream, a tributary of the Clwyd in the ravine in which they are situated. These facts suggest the following as the probable changes indicated by the deposits in the caverns:—The lowest deposit in the caverns, consisting almost entirely of local materials, was introduced into them by the river which then flowed in the valley at a very much higher level than at present. As time went on the valley deepened, and the caverns were above the reach of the floods. They then became the abode of hyænas and other beasts of prey. Subsequently there was a period of great submergence, and when the caverns were on a level with the sea, they were filled with sandy materials and the bones were embedded in it. The following are the results which have to be accounted for: (*a*) The infilling of the caverns by local gravels; (*b*) the occupation of the caverns by beasts of prey; (*c*) the formation

of the stalagmite; (*d*) the breaking up of the stalagmite floor and the introduction of the boulder clay. The position of the caverns almost at the crest of a ridge of carboniferous rocks makes it clear that the boulder clay could not have been introduced by streams, therefore the only conclusion I can arrive at is that during a period of great submergence, either during or subsequent to the glacial epoch, the material was introduced by marine action.

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10. *Note on Specimens of Fish from the Lower Old Red Sandstone of Forfarshire. By the* Rev. Hugh Mitchell.

The author stated that at the meeting of the Association in 1859 he exhibited specimens of fish which were afterwards described by Sir P. Egerton in the Tenth Decade of the Geological Survey. With these specimens was a beautiful spine, the relations of which were unknown, but of which other portions have since been found. The author submitted descriptions which he regarded as sufficient to justify the founding of three new species. The specimens were from Farnell and Turin.

SATURDAY, SEPTEMBER 12.

The following Papers and Report were read:—

1. *The Elgin Sandstones. By* J. Gordon Phillips.

The question of the age of the reptiliferous sandstones of Elgin is not yet settled. Murchison and Sedgwick decided on stratigraphical grounds that they belong to the Old Red formation, which was afterwards confirmed by Palæontology. Later discoveries, however, of reptilian remains (*Stagonolepis, Telerpeton,* and *Hyperodapedon*), raised the question of the age, one party maintaining that the reptiles were of Triassic origin, and the other, of the upper beds of the Old Red. The opinions of the supporters of the Triassic theory were gradually accepted, owing to palæontological discoveries, and, indeed, so sure were palæontologists they were right, that one said if the sandstones turned out to be Old Red, he would give up geology altogether, and another said he would not believe they were Old Red until he saw a reptile with a *Holoptychius* in its mouth. There were a few geologists who still clung to the old belief, among them being Dr. Gordon of Birnie and the late Professor Nicol. The question, however, has again been opened by the discovery of reptilian remains and of Holoptychian remains in the same quarry, the latter underlying the former, but there is a bed of conglomerate, five feet thick or thereabouts, between the two deposits. This bed has died out in the meantime, and it is doubtful if it will reappear; the Old Red may be found passing under the reptiliferous in natural order right on the coast.[1] Indeed there is evidence of the existence of *Holoptychius* a little west of Stotfield, in ground which has hitherto been deemed purely reptilian, which tends to confirm that idea. This quarry is situated on the ridge which runs south-west by west to north-east by east in the immediate vicinity of Elgin, and called Cutties Hillock. In Professor Judd's admirable paper on the 'Secondary Rocks of Scotland,' published in 1873, he has the two systems faulted against each other above Findrassie, but the fact of reptiles and a *Holoptychius nobilissimus* having been found in this quarry in deposits apparently conformable shows there is no such powerful fault. But when Professor Judd's paper was written no other conclusion could be arrived at. He knew that reptilian remains had been got immediately to the north of the

[1] Since the above was written the workmen have, on the north side of the quarry, gone down into sandstone, which I regard as being identical with that containing *Holoptychius*, and, in my opinion, the two deposits are lying apparently perfectly conformable, with no conglomerate between. It seems to me to have died out altogether, only an occasional pebble appearing.

ridge at Findrassie, and he also knew that at least one Old Red fish had been got at its southern base at Laverock Loch, so that it was the most probable explanation to indicate the presence of a fault. And indeed, at the east end of the ridge near Bishopmill, there is evidence of disturbance, though it in no way affects the quarry at Cutties Hillock. After the quarry (Cutties Hillock) was opened, the lessees, for the purpose of finding out the building qualities of the stone, sank a pit through the bed of conglomerate, mentioned above, a distance of about 22 feet, and in this pit was found a *Holoptychius*. The pit was subsequently filled up, as the stone was not found suitable for building purposes. This necessitated the cutting of a trench again into the Holoptychian sandstone, to see if the overlying beds are conformable or unconformable, which is now being proceeded with.[1] In the quarry there is also a sand dyke dividing it, but reptilian remains have been found on both sides. What these reptiles are has not yet been determined, though Huxley is understood to have said that he believed one of them to be *Dinosaurian*. All these reptilian remains, with the exception of one, were found about the same level in the quarry, indeed so much is this the case that the workmen call it 'the fossil joint.' The texture of the Holoptychian sandstones and the reptiliferous sandstones is different. The former is fine, and the laminæ are well marked, while in the other it is more rough and angular, but they appear to have been both drawn from the same sources of granite waste. We have not made microscopic sections, but have examined the sand of which the two deposits are formed, and there is little apparent difference. They are composed of quartz, felspar, and mica, the reptiliferous being, if anything, a little more felspathic in character. Such a case, so far as we know, is unique. Reptile-bearing beds have never before been found lying on the Old Red and apparently conformable. The question is, are the reptiliferous beds Triassic or Upper Old Red? Looking at the matter from an Old Red point of view, it is difficult to understand why reptiles could not have existed in the Upper Old Red if the conditions of life were favourable, and we feel no assurance that the conditions of life should not have been favourable when the Elgin sandstones were deposited. If they are Triassic, what has become of the vast periods which lie between the two systems, and why should these reptiles be confined to a few miles of north-eastern Scotland in the vicinity of Elgin? The palæontologist would answer that some of these reptiles have been found in the Trias in other parts of the world (England, Africa, and India), and that Old Red fishes and reptiles had never been found associated together in the same beds. All that we ask is that the question may be kept open for a time, so that all possible evidence may be obtained. We acknowledge the full weight of palæontological evidence, and all that geologists owe to that great science, but it is possible that in some cases it may be stretched too far. All that we wish to ascertain is the truth, and with present light we cannot say that it has been reached. We want more proof.

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2. *Preliminary Note on a new Fossil Reptile recently discovered at New Spynie, near Elgin.* *By* Dr. R. H. Traquair, *F.R.S.*

Of this most important fossil the author had as yet only seen a photograph, submitted to him by Professor Judd, F.R.S., the President of the Section. This photograph represents pretty nearly a vertical longitudinal section of a reptilian skull, of which one very prominent feature is the presence in the upper jaw of a large conical tusk projecting downwards and forwards, immediately behind the premaxillary part of the cranium. This tusk is seen only in impression, but the cast of the internal cavity, which is well shown, indicates that it grew from a permanent pulp. No evidence of any other teeth is visible, and the whole appearance of the skull as seen in the photograph, with the position and shape of the tusk, indicate that the reptile here represented, if not actually belonging to the genus *Dicynodon*,

[1] This trench, when finished, was examined by Professor Bonney, Professor Judd, and myself. There was the appearance of a very slight unconformity in my opinion, but such appearances frequently occur in the Elgin Sandstones caused by false bedding.

is certainly a member of the group of *Dicynodontia.* Geologists will not underrate the value of this discovery in its bearing on the question of the age of the reptiliferous sandstone of Elgin.

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3. *Report on the Fossil Plants of the Tertiary and Secondary Beds of the United Kingdom.*—See Reports, p. 396.

MONDAY, SEPTEMBER 14.

The following Papers were read :—

1. *The Highland Controversy in British Geology : its Causes, Course, and Consequences. By* Professor CHARLES LAPWORTH, *LL.D., F.G.S.*

PART I.

The author gave a *résumé* of the views of the earlier geologists respecting the geological age and possible mode of formation of the Highland Metamorphic rocks, and sketched in brief the rise and progress of the controversy between Sir R. Murchison and his followers on the one hand, and Professor Nicol of Aberdeen on the other, till its temporary close in 1855 by the publication of the Highland Memoir of Murchison and Geikie. He then reviewed the re-opening of the controversy by Dr. Hicks in 1877, and the work of the Archæan geologists, up to the date of publication of Dr. C. Callaway's paper in 1883, in which Nicol's view of the great physical break between the Palæozoic rocks and the Eastern or Upper Gneissic series was shown to be correct; but the so-called Eastern Gneiss was provisionally erected into a new Archæan system, having the Arnaboll Gneiss as its lower member.

The author next gave a summary of his own views, as deduced from his personal study of the Durness-Eriboll district in 1882 and 1883, illustrating them by coloured maps and sections. He held that (exception being made of the local Torridon sandstone) the only rock-formations in the Durness-Eriboll area are, as Nicol originally contended,—(1) the Archæan or Hebridean gneiss,and (2) the Palæozoic quartzites, fucoid beds, and limestones.

There is no conformable ascending succession from the Palæozoic rocks into the Eastern Metamorphic series. The line of contact is, generally speaking, a plane of dislocation, and where this is wanting the Palæozoic rocks rest unconformably upon one of the members of the Eastern Gneiss. The present physical relations of the Eastern Metamorphic series are the effect of lateral crust-creep, by which the Eastern Metamorphic rocks have been forced over the Palæozoic rocks to the west, often for many miles. This Eastern Metamorphic series is composed of two petrological members, the *Arnaboll gneiss* to the west, and the *Sutherland schists* and gneiss to the east, having between them a series of *variegated schists* possessing characters common to both. The Arnaboll gneiss is simply the easterly extension of the Hebridean of the west. The remaining gneisses and schists of the Eastern Metamorphic series are mainly composed of remetamorphosed Hebridean, with included patches of igneous and Palæozoic material. The planes of schistosity which divide the layers of the Upper Gneissic series are not planes of bedding, but planes of dislocation. The present dip, strike, and mineralogical characteristics of these rocks have been given to them since Silurian times, by the agency of the great earth movements. In some instances the original structures of the rocks are still recognisable ; frequently, however, they are more or less obliterated, the old minerals have disappeared as such, and new minerals have been developed. The Eastern Gneissic series of this area has thus no pretension whatever to the title of a sedimentary rock-system. It is a petrological rock-massif, a metamorphic compound, composed of local elements of different geological ages. In all their essentials

these views appear to agree with those worked out independently by Messrs. Peach and Horne in 1884.

PART II.

In the second part of his paper the author gave a summary of the work accomplished among the metamorphic rocks of the Alps and Eastern Germany by Heim and Lehmann, and described the several types of rock metamorphism found in the Eriboll district, as worked out by himself.

The Arnaboll (Hebridean gneiss), can be traced stage by stage from spots where it retains its original strike and petrological characters, to others where it acquires the normal strike and mineralogical features of the ordinary Sutherland schists. The old planes of schistosity become obliterated and new ones are formed; the original crystals are crushed and spread out, and new secondary minerals (mica and quartz) are developed. The most intense *mechanical* metamorphism occurs along the grand dislocation (thrust) planes. The gneisses and pegmatites resting on that plane are crushed, dragged, and ground out into a finely laminated schist (*mylonite*; Gr. *mylon*, a mill), composed of shattered fragments of the original crystals of the rock, set in a polarising cement of secondary quartz, the lamination being defined by minute inosculating lines (fluxion lines) of kaolin or chloritic material, with secondary crystals of a micaceous mineral. Whatever rock rests immediately upon the thrust-plane, whether Archæan, Igneous, or Palæozoic, &c., is similarly treated, the resulting mylonite varying in colour and composition according to the material from which it is formed.

The variegated schists, which form the transitional zones between the Arnaboll gneiss and Sutherland mica-schists, are all essentially mylonites in origin and structure, and appear to have been formed along great dislocation planes, some of which still show between them patches of recognisable Archæan and Palæozoic rocks. These variegated schists (phyllites or mylonites), differ locally in composition according to the material from which they have been derived, and in petrological character according to the special physical accidents to which they have been subjected since their date of origin, forming frilled schists, veined schists, glazed schists, &c. &c.

The more highly crystalline flaggy mica-schists &c. which lie immediately to the east of the zones of the variegated schists, appear to have been made out of similar materials to those of the variegated schists, but to have been formed under somewhat different conditions. They show the fluxion-structure of the mylonites, but while the differential motion of the component particles seems to have been much less, the chemical change was much greater. In some of these crystalline schists (the augen-schists), the larger crystals of the original rock from which the schist was formed are still individually recognisable, while the matrix now containing them is a secondary crystalline matrix of quartz and mica arranged in the fluxion-planes. While the *mylonites* may be described as microscopic pressure-breccias with fluxion-structure, in which the interstitial siliceous and kaolinitic paste has only crystallised in part; the *augen-schists* may be described as pressure-breccias with fluxion-structure, in which the whole of the interstitial paste has crystallised out. The *mylonites* were formed along the thrust-planes, where the two superposed rock-systems moved over each other as solid masses, the *augen-schists* were probably formed in the more central parts of the moving system, where the all-surrounding pressure forced the rock to yield somewhat like a plastic body. Between these augen-schists there appears to be every gradation, on the one hand to the mylonites, and on the other to the typical mica-schists composed of quartz and mica.

Like the mylonites, the crystalline augenites and micalites present us with local differences in chemical composition (calcareous, hornblendic, quartzose, &c.) They also show corresponding structural varieties due to secondary changes (frilled, veined, glazed, &c.), as well as others due to the presence of special minerals (garnet, actinolite, &c. &c.).

2. *The Geology of Durness and Eriboll, with special reference to the Highland Controversy. By* B. N. Peach, *F.R.S.E., and* J. Horne, *F.R.S.E.*

With the permission of the Director General of the Geological Survey, the authors gave an outline of the geological structure of the Durness-Eriboll region, illustrated by a series of horizontal sections. They showed that the Silurian strata of Durness are arranged in the form of a basin bounded on the east side by powerful faults disconnecting them from the same series in Eriboll. The order of succession in the two areas is identical from the basal quartzites to the horizon of the Eilean Dubh limestone group. On the west side of Loch Eriboll the basal quartzites rest unconformably on the Archæan gneiss, but on the eastern shore there is conclusive evidence of the repetition of various members of the Silurian series by a remarkable system of reversed faults culminating in a great dislocation which has thrust the Archæan gneiss over the truncated edges of the quartzites, fucoid beds, serpulite grits, and basal limestone. Reference was made to the effect of these mechanical movements on the Silurian rocks and to the development of new planes of schistosity in the gneiss above the thrust plane. At intervals, small patches of the basal quartzites are met with throughout this mass of Archæan gneiss, which are abruptly truncated by great reversed faults, but in the district between Eriboll and Assynt the whole Silurian succession from the basal breccia to the lowest limestone occurs repeatedly above the first great thrust plane, separated by wedges of highly sheared gneiss. It was shown that the alteration produced by each successive displacement gradually becomes more pronounced as the observer passed eastwards across the area. The old north-west strike of the Archæan gneiss gave place to a new foliation running more or less parallel with the strike of the thrust planes; the felspathic basal quartzites and the 'pipe-rock' pass into quartz schists and mica schists, and the Silurian limestone is felted with the crushed Archæan gneiss. Reference was next made to the outcrop of the great thrust plane extending from the Whitten Head Coast far to the south, which ushers in a highly schistose series with a N.N.E. and S.S.W. strike. After describing the lithological characters and order of succession of the eastern schists, the authors stated that the new planes of foliation had been superinduced by the mechanical movements that took place between Lower Silurian and Old Red Sandstone time, and that along these new planes a rearrangement and recrystallisation of mineral constituents took place, resulting in the production of crystalline schists. Applying the knowledge thus obtained from the study of the eastern schists to the undisturbed Archæan masses, they had found conclusive evidence of similar mechanical movements in Pre-Cambrian time. Each plane of schistosity exhibits the parallel lineation like slickensides trending in the same direction over a vast area, while the minerals were oriented along these lines. From a consideration of these phenomena the authors inferred that regional metamorphism need not necessarily be confined to any particular geological period, and further that the planes of foliation or schistosity in those areas which had been subjected to regional metamorphism were evidently due to enormous mechanical movements which had induced molecular changes in crystalline and clastic rocks.

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3. *Preliminary Note on some Traverses of the Crystalline District of the Central Alps. By* Professor T. G. Bonney, *D.Sc., LL.D., F.R.S., Pres.G.S.*

During the past four years I have made several traverses of the Central Alps from north to south, and venture to lay before the Section the general results as bearing in some respect on the geology of the Highlands.

1. The ordinary rules of stratigraphy as learnt from most lowland districts are commonly quite inapplicable to the Alps. The most highly crystalline and the older beds often form the higher parts of a mountain region, the newer the lower. The newer beds frequently appear to underlie and dip regularly beneath the older. Gigantic folds, overturns, and overthrust faults abound. The true stratigraphy of

a district can only be worked out by the exercise of patient and cautious induction from observations extended over a wide area.

2. The non-crystalline rocks of the Alps are of various ages. There are some of Carboniferous age, but the great period of continuous deposition generally begins with some part of the Trias. The conglomerates, which often occur at the base of the non-crystalline deposits, indicate that the principal metamorphism of the crystalline series was anterior to both these epochs. There is at present no reason to suppose that either in the Central Alps or for some distance on each side there are any representatives of the earlier Palæozoics. I believe that the conglomerates at the base of the Carboniferous contain fragments of the later crystalline rocks of the Alps as well as of some of the earlier—though I do not assert that these crystalline rocks have undergone no modifications since Carboniferous times.

3. In the heart of the principal Alpine chains, and apparently at the base of everything, are coarsely crystalline gneisses. These differ little from granites, except that they generally—almost always—exhibit a certain foliation, and occasionally seem to be interbedded with thin seams of micaceous schists or flaggy fine-grained beds.

4. On examining these latter we find reason to believe that they are generally due to crushing. Their strike agrees with that of the apparent foliation in these older rocks, and with that of a foliation which is also present in the newer crystalline rocks. This corresponds with the strike of the main physical features of the district, and with the cleavage in the included troughs of sedimentary rock. It runs for great distances with remarkable uniformity, *e.g.*, from the Maderanerthal to the upper part of the Lukmanier Pass the strike of this foliation does not materially vary from W.S.W.-E.N.E.

5. This apparent foliation is due to the development of extremely thin films of a micaceous mineral. In many cases it causes the rock to bear the aspect of a highly micaceous schist; yet, on examining a transverse section, it is seen distinctly to be a crushed gneiss; *i.e.*, though so conspicuous, it is a mere varnish. As it thus differs materially from a true foliation, it would be convenient to give it a name, and I should propose to call it the 'sheen surface.' It is, in fact, a kind of 'cleavage foliation,' that is, a foliation due to cleavage, and subsequent to it. But though from certain points of view so conspicuous, its minerals often constitute a very small part of the mass of the rock.

6. The pressure which has produced this 'sheen surface' has in many cases affected the orientation of the minerals, which are present in the true 'foliation' layers of the more distinctly foliated, *i.e.*, mineral-banded, rocks. It has affected these minerals as pressure affects the constituents of a sedimentary rock.

7. In the crystalline schists very commonly the 'sheen surface' corresponds with the original foliation surface, as in the slates the cleavage sometimes does with the bedding. This is due to the fact that the axes of the great folds often make a very high angle with the horizon. It may, however (like a cleavage surface), be seen crossing the foliation at all angles.

8. Thus a non-foliated crystalline rock may be rendered to some extent foliated by pressure (followed by a certain amount of mineralisation); *i.e.*, some gneisses may be formed by crushing from granites, some schists out of other igneous rocks. It may obliterate an earlier foliation, or it may intensify it, or it may produce an independent and more fissile foliation.

In this sense gneiss may be said to pass into granite, because a rock which is now, both macroscopically and microscopically, a gneiss may prove to be a granite which has in some parts yielded to pressure more than in others.

9. As we pass outwards from the great central granitoid masses we come to gneisses and schists where the evidence of some kind of stratification becomes more marked; bands of crystalline limestone, quartzite and granulite being associated with mica schist of many kinds—simple, garnetiferous, staurolitic, actinolitic, and the like—the bands of different mineral character and composition varying from mere streaks to layers which are many yards in thickness. In fact, the above-named rocks are associated exactly as limestones, sandstones, and clays are associated in the ordinary sedimentaries.

10. Although the crushing of a crystalline rock *in situ*, or the squeezing and shearing of a breccia or conglomerate of crystalline fragments, occasionally gives rise to local difficulties, these are on a small scale, and sedimentary beds belonging to the Palæozoic or later periods of deposition are generally readily distinguishable from the whole of the crystalline series. Though folded and faulted in the most extraordinary manner, the members of the two series can generally be separated, and in the Alps there is no evidence of a mingling of the one with the other in the process of rolling out or squeezing together; so that after patient study and microscopic examination we can generally decide without hesitation whether a particular set of rocks has originated from the crystalline or the sedimentary series. I do not say that we can always decide whether a schist or a gneiss has originated from an igneous rock or from an older schist or gneiss, but I think that in the Alps we can say that it has originated from one of these. Fortunately, intrusive rocks are very rare in the Palæozoic and later deposits in this part of the Alps.

11. Thus, although the Tertiary metamorphism of the Alpine rocks is very important, it is more pretentious than real, and its effects seem to have been the greatest where it has found a rock already crystalline to act upon. Hence I believe that every true gneiss and schist in the Alps is much older than the Carboniferous, and is probably older than any member of the Palæozoic period.

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4. *Some Examples of Pressure-Fluxion in Pennsylvania.* *By* Professor H. Carvill Lewis.

The three localities in Pennsylvania described in this paper lie in an area which had been especially studied by the author for some years back, and had led him to conclusions similar to some of those recently announced as the result of studies in north-western Scotland, which have justly attracted widespread attention.

1. A zone of ancient crystalline rocks extends across south-eastern Pennsylvania, near Philadelphia, which is generally believed to underlie the lowest Cambrian strata and to be of Archæan age. This zone is about a mile wide where it crosses the Schuylkill river, south of Conshohocken, and it is from this point to Westchester, some 20 miles westward, that the present remarks especially apply. Although in many portions exhibiting a distinct gneissic lamination, the rocks of this zone are held by the author to be of purely eruptive origin, consisting of syenites, acid gabbros, trap granulites, and other igneous rocks, often highly metamorphosed. It is the outer peripheral portion of this zone to which attention is here directed.

While the rocks are massive in the centre, this outer portion has been enormously compressed, folded and faulted, with the result of producing a tough, banded, porphyritic *fluxion gneiss*, identical with the 'milonite' of Lapworth or the 'sheared gneiss' of Peach and Horne. So perfect is the fluxion structure that the rock resembles a rhyolite. As in the 'banded granulite' of Lehmann, elongated felspar 'eyes' lie in flowing streams of biotite grains and broken quartz, the streams often parting and again meeting around the porphyritic 'eyes.' Occasional crystalline eyes of hornblende remain, but most of it has been converted into biotite.

A point of especial interest is that the felspar of the 'eyes' is quite colourless and free from inclusions, like the sanidine of recent lavas; while on the other hand the felspars of the inner and massive portions of the zone, out of which this outer portion has been reformed by pressure fluxion, are full of inclusions and have the 'dusty' appearance so common in ancient felspars. The fresh-looking felspar eyes have therefore very possibly been subsequently formed as the result of a *recrystallisation* of the old material under the influence of *pressure fluxion*. In similar manner the biotite has been made out of the old hornblende, garnets have been developed, and the quartz has been granulated and optically distorted by pressure.

The influence of pressure is also seen in certain Cambrian strata in the immediate vicinity, where a sandstone containing cylindrical casts of *Scolithus linearis*,

apparently identical with the 'pipe-rock' of north-western Scotland, has, like it, been compressed to such a degree that the vertical casts are flattened out and elongated in the direction of lamination to several times their original length. In the same sandstone quartz pebbles have been pulled out and flattened, while sericate has been largely developed along the cleavage planes. The pressure can be shown to have been directed mainly from the south-east.

2. The second locality is in the midst of the Laurentian area of Bucks County, and is known as Van Artsdalen's Quarry. A mass of crystalline limestone is here mingled with an eruptive diorite in such manner as to show that it had actually flowed like an igneous rock and had caught up inclusions. The results of extreme metamorphism are exhibited in the development in the limestone of graphite, ekebergite, and other minerals. The chemical changes and interchange of elements which might result from a loosening of molecular combinations under extreme pressure and their subsequent 'regelation' into new compounds were discussed as among the phenomena of mechanical metamorphism.

3. As an American instance of the conversion of an intrusive diabase dyke into amphibolite schist, analogous to the case recently described by Teall, a long narrow belt of sphene-bearing amphibolite schist in the city of Philadelphia was adduced. This belt, with distinctive mineralogical characters, cuts across the metamorphic mica schists of the region unconformably, and is believed by the author to be a highly metamorphosed intrusive dyke of Lower Silurian age. The original augite or diallage has been completely converted into fibrous hornblende, and the influence of pressure is shown in the perfectly laminated character of the schist, in the close foldings produced, and in the minute structure of the rock. Some interesting details of the latter having been photographed, diagrams constructed from these were exhibited. These showed that the rock was traversed by a parallel series of slips and crushings, and that about such lines of faulting and crushing there was a peculiar arrangement of the lines of hornblende crystals not very unlike the arrangement of iron filings about the poles of a magnet, such as could not be satisfactorily explained by any theory of aqueous deposition, but pointed to a lamination by pressure.

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5. *On Slaty Cleavage and allied Rock Structures, with special reference to the Mechanical Theories of their Origin. By* ALFRED HARKER, *M.A., F.G.S.*—See Reports, p. 813.

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6. *On Irish Metamorphic Rocks. By* G. HENRY KINAHAN, *M.R.I.A.*

This paper is an epitome of what is known as to the age of the Irish metamorphic rocks. The author gives ten Irish localities in which the rocks lithologically are more or less identical with the Laurentian rocks of America. Of each locality a short description is given, and where the age of the rocks is positively proved it is stated, while in the other cases the probable age is suggested. He also points out that while in some cases lithological characters are taken as a sure test of Laurentian age, in other cases they are ignored, by which means many rocks eminently lithologically similar to some of the Canadian rocks have been excluded from the so-called Irish Laurentians.

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7. *On Rocks of Central Caithness. By* JOHN GUNN.

The term 'Central Caithness' is intended to embrace most of the parish of Halkirk and part of the parish of Watten.

The upper part of the parish of Halkirk is covered by drift gravel, underlying peat. At Loch More flagstones are presented. Below the lake may be traced the banks of what was once a great river. At Dirlot the rocks are sandstone, granite, gneiss, gneissic conglomerate, and limestone. At Dalmore the right bank of the Thurso is composed of boulder clay, the left of gravel. Here is seen a chain of

moraines, composed of granitic gravel and sand. At Tormsdale a vein of some cinder-like material occurs. The flagstones at Poll a' Chreagan are covered with freestone, as also at Dale Bridge on the right bank of the river. On the left the flags lie exposed in great tabular masses, overlying limestone. At the top of the Mill Pool are the remains of a natural dam. Below this pool a band of freestone once crossed the bed of the river. At Dale are shifting beds of gravel, and here the river is continually changing its course. Below Pollihour flags again appear, and opposite Scots Calder are banks of boulder clay, the boulders therein being very distinctly striated. Great masses of flagstone block up the bed of the stream at Gerston. At Halkirk the cliffs are coated with red ochre.

Granite is not visible at Dorrery, as has been stated by at least one writer, but it does not appear to lie at any great depth below the flags.

At Achanarras a curious fossil *Coccosteus* is found in a small slate quarry.

East from Spittal the angle at which the rocks dip gradually diminishes, and at Lanergill reaches its nearest approach to a dead level.

Drift gravel prevails in the neighbourhood of Halsary, and also down part of Strathbeg, where the banks of the ancient river may again be traced. Here the Dalmore moraines are continued.

No evidence of volcanic action can be gathered from an examination of the rocks of Central Caithness, but the district presents a fair field for the study of erosion by ice, air, and water.

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8. *On some Rock Specimens from the Islands of the Fernando Noronha Group.* *By* Professor A. Renard, *LL.D., F.G.S.*

The rock specimens described in this communication were collected by J. G. Buchanan, Esq., during the voyage of the 'Challenger.' The islands have been described by Darwin in his 'Geological Observations on Volcanic Islands' (2nd edit., p. 27). The author, after having explained the geological structure, gave lithological descriptions of the chief types of the rocks, which may be referred to the phonolites (St. Michael's Mount). These phonolites are composed of sanidine, augite, nepheline, hornblende, magnetite, nosean, and titanite.

The rocks of Rat Island are basalts with nepheline. The constituent minerals are augite and olivine. The ground-mass is almost entirely composed of nepheline; biotite and apatite occur as accessory constituents. The little island known as Platform Island is also basaltic, with a doleritic texture. It is composed of labradorite, augite, olivine, magnetite, and biotite. This rock has undergone alterations.

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9. *On the Average Density of Meteorites compared with that of the Earth.*[1] *By the* Rev. E. Hill, *M.A., F.G.S.*

The average density of the meteorites which fall on the earth is attempted to be calculated. Different methods described give as results 4·55, 4·58, 4·84, 5·71; the last value being influenced by the size of one particularly large metallic specimen. The average density of the earth is usually regarded as 5·6. Meteorites are samples of the materials of space, and a mass of them would aggregate into a body of density not widely differing from that of the earth. The densities of the other planets are not inconsistent with a like origin. Consequently any theory of the genesis of the earth from pre-existing materials involves a probability that an important part of its nucleus is metallic.

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[1] *Geological Magazine*, 1885, p. 516.

TUESDAY, SEPTEMBER 15.

The following Papers and Reports were read:—

1. *Notes on a recent Examination of the Geology of East Central Africa. By* Professor HENRY DRUMMOND, *F.R.S.E., F.G.S.*

The district traversed included the littoral belt at the mouths of the Zambesi and Quilimane rivers, the region watered by the Shirè river from its source in Lake Nyassa to its terminus in the Zambesi, the Shirè highlands, and the western shore of Lake Shirwa, the rock-basin of Lake Nyassa, and the southern portion of the Nyassa-Tanganyika plateau. The first geological feature, on entering the country from the Zambesi, was an ancient coral-reef studded with sponges, which is exposed on the Qua-qua river above Mogurrumba. A few miles further inland sedimentary rocks are reached at Mopeia. A poor section occurs in the Zambesi above Shupanga, the beds consisting of red and yellow sandstones with intercalated marls and fine conglomerate. No organic remains were discovered, but the section may belong to the series found in a similar relation along almost the whole coast from the Cape to Zanzibar and northwards. The first hills reached, at Morumballa, consist of a very white quartzite. A hot spring occurs here, and one or two others are found on Lake Nyassa. Of the coal which Livingstone mentions on the Lower Shirè no trace was found after repeated examination. Dark rocks, of intrusive origin, occur at the locality. The coal on the western shore of Lake Nyassa, discovered by Mr. Rhodes, and described by Mr. James Stewart, C.E., was visited, and found to be of inferior quality, and existing only in small quantity. The seven-foot seam described by Stewart was really composed of thin beds of alternately carbonaceous and argillaceous matter.

The whole country from the Shirè a hundred miles above its junction with the Zambesi, the whole Shirè highlands, the western shore of Lake Nyassa, and the plateau between Nyassa and Tanganyika for half its length, consisted, with one interruption, of granite and gneiss. The character and texture of this formation persisted with remarkable uniformity throughout this immense region. The granite was an ordinary grey granite, composed of white, rarely pink, orthoclase; the mica of the biotite variety. Sometimes the gneiss persists over a large area, sometimes the granite, while frequently the two alternate within a limited space. Associated minerals were rare. Intrusive dykes of dolorite occur on the southern border of the Shirè highlands above Katunga. The only volcanic rocks met with were those already described by Mr. Joseph Thomson at the north end of Lake Nyassa. The only break in the granitic series occurs on the north-west shore of Nyassa, near Karonga. On the Rukuru river is found a well-marked series of stratified rocks, consisting of thin beds of very fine sandstone and shales, and occasional beds of limestone. After considerable search these beds were found to contain numerous fossils, including fish, mollusc, and plant remains. These fossils have not yet been examined, so that the age is uncertain, but the deposit is probably lacrustrine. Lake Shirwa is drying up rapidly, and there is evidence of a former and much larger Shirwa, which may have been confluent with Lake Nyassa. Lake Pomalombe is shoaling fast, and is the remains of a once greatly extended Lake Nyassa. Lake Nyassa lies in an immense rock-basin of granite and gneiss, the greatest depth being towards the high plateau on the northern end. After careful examination of this whole region no trace of glaciation, no boulder-clay, moraine, striation nor glaciated outline were anywhere to be detected.

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2. *Report on the Rocks collected by H. W. Johnston, Esq., from the upper part of the Kilima-njaro Massif. By* Professor T. G. BONNEY, *D.Sc., LL.D., F.R.S., Pres.G.S.*—See Reports, p. 682.

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3. *Some Results of the Crystallographic Study of Danburite. By* Max Schuster.

In studying the characters of the faces and the structure of the Danburite crystals found in Switzerland, the author had met with vicinal faces of a peculiar kind, for which he proposed the term 'transitional faces' ('Tschermak Min. Mittheil.' vi. 1884, p. 511). Attention was called to the fact that these faces are easily affected by those causes which produce an unequal development of faces otherwise symmetrically disposed, and an illustration was given of the way in which their indices are numerically related to those of the principal faces of the crystal.

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4. *American Evidences of Eocene Mammals of the 'Plastic Clay' Period. By* Sir Richard Owen, *K.C.B., F.R.S., F.G.S.*

In the year 1843 a fragment of a lower jaw with one entire molar of a mammal was dredged up off the Essex coast. A canine tooth of the same was found in a well-sinking near Camberwell, in piercing the 'plastic clay.' The author had described the above as belonging to an animal of the Lophiodont family, and proposed for it the generic name Coryphodon. Shortly afterwards De Blainville had noticed certain fossils as 'probably Coryphodont,' but had referred them to *Lophiodon anthracotherium.* Ten years later Professor Hebert had recognised two species of *Coryphodon* in the plastic clay of France. Explorations by Leidy, Marsh, and Hayden, in the Mauvaises Terres of Nebraska had led to the discovery of a large hoofed mammal allied to *Coryphodon*, to which the name *Titanotherium* had been given; and Professor Cope has now recognised, from Evanstown, Wyoming, seven species of *Coryphodon.* From these materials, which have been rendered accessible to European palæontologists by the superb volume of reports recently issued by the United States Government, the author is enabled to give a general description of this family of hoofed mammals of large size, which flourished in early eocene times. To the details of this the major part of the paper is devoted.

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5. *Discovery of Anurous Amphibia in the Jurassic Deposits of America. By* Professor O. C. Marsh.

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6. *Third Report on the Fossil Phyllopoda of the Palæozoic Rocks.* See Reports, p. 326.

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7. *On the Distribution of Fossil Fishes in the Estuarine Beds of the Carboniferous Formation. By* Dr. Traquair.

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8. *Some Results of a detailed Survey of the Old Coast-lines near Trondhjem, Norway. By* Hugh Miller, *F.G.S.*

During a short visit to Norway in October 1884, it appeared to the author that the best way to help to a solution the vexed questions connected with the coast-terracing of Norway was to execute a careful survey of a few square miles of some suitable coast region upon a sufficiently large scale. The neighbourhood of Trondhjem is remarkably well suited to this purpose. The map employed was partly a municipal chart on the scale of $\frac{1}{10000}$, and partly an enlargement of the Ordnance Map. The limit of all the terraces and marine deposits is the famous 'strand line' west of the town, a double range of old-coast cliff cut in the rock of the mountain side. Its upper line is 580 feet above the sea,[1] and answers

[1] R. Chambers's measurement of the lower line in 1849 was 522 feet by level and staff. To this is added Professor Mohn's estimate (58 feet) of the interval between the two. The latter proves to be excessive.

to the 'marine limit' over Norway generally. Numbers of level terrace-lines have been incised—chiefly in greenish clays, like brick-clays—all along the arable slopes east of the town between this rock-terrace and the sea. Above the Bay of Leangen, two miles east of town and river, and far beyond all erosive influence of the latter, thirty of these lines were mapped one above another in the first 300 feet of ascent, a distance of one and a half mile. Many of these are small but extremely distinct, the earthy clays being well suited to retain sharp impressions of successive sea-margins, which these unequivocally are. The present coast-line, neatly etched out by the waves in Trondhjem and Leangen bays, is the key to these tiers of older ones. It also resembles them in having made little or no impression where the coast becomes rocky, the lines of incision in both cases stopping short at once when they reach the harder material. The old coast-lines are most numerous in well-sheltered positions. Thus a single pair of large terraces in an exposed situation east from Christiansten, where they face the open water of the fjord and the prevalent north-westerly storms, is represented in the recess above Leangen Bay by ten or twelve. The same fact is brought out on rising from this recess to the higher and more exposed ground. Thus, while thirty-three or thirty-four terraces are mapped below 350 feet (approximate) elevation, only nine or ten appear between that level and the rock-terraces of the upper marine limit, the numerical average height of each terrace thus rising by more than a half. In recesses of the coast further east, but beyond the map, these upper terraces seem to be preserved in considerably greater numbers. The number actually mapped was forty-three, or with the two rock-terraces, forty-five. The largest number of terraces hitherto described at any one place in Norway seems to have been less than half that number.

Some of the general conclusions of the author are as follows:—(1) These terraces are all post-glacial, *i.e.* formed subsequent to the rock-glaciation of the district. This is confirmed by the condition of the high coast-cliff, which has been cut in ice-rounded rock, but is not itself glaciated. It appears, however, from the fauna of the raised shell-banks of the country (as worked out by Sars and Kjerulf), in which recent shells do not rise above 380 feet, that the seas of the upper levels were still glacial; and, though the Trondhjem fjord was free from land-ice, other deeper fjords and higher coasts may still have had glaciers coming into conflict with the sea, and producing the glaciated rock-terraces described elsewhere by Sexe. All the evidence obtained discountenances Sexe's view that these rock-terraces were cut out by glaciers, as well as Carl Petersen's that they were rasped out by floating ice coasting the shores. On the clay terraces coast-ice has left no more sign of its presence than the winter freezing of our British rivers leaves upon our river terraces. (2) If the country was upraised by a succession of elevatory jerks, as supposed by most geologists from Keilhau downwards, most of these would seem to have been small—much smaller, at least, than is supposed by Kjerulf. It is improbable that even Leangen Bay was secluded enough to contain a record of all the original coast-lines. The longer pauses and greater storms may have effaced an unknown number of them by a process of excision exemplified in all its stages by the map. It is hard to say, in fact, where the subdivision, if it could be fully traced out, would end. The smaller terraces remind the eye of the incised lines and little planes engraved on the sandbanks bordering the rivers after a flood, where there is no periodicity in the subsidence of the waters. (3) The preservation or excision of the terraces thus seems to depend as much upon local circumstances —exposure to storms, resistance of coast-line, &c.—as upon anything else. It is impossible at present to predicate which of them shall in any given place remain. Whether elevation by jerks, therefore, be postulated or not, all hope of correlating these terraces throughout the country must be deferred until their heights have been accurately determined by level. The measurements hitherto made, not even excepting those of Professors Kjerulf and Mohn, are probably inadequate for the purpose. This observation seems to apply also to the terraces graven in rock. In their aneroid measurements of the upper strand-line at Trondhjem these observers differ by fifty-five feet. (5) On entering the mouth of the Trondhjem Valley the terraces come under an influence other than that of the sea-waves. The valley was

worked out, in deposits partly levelled out by the sea, according to the laws of river terracing under the accelerating influences of a falling sea-level. The processes of automatic river terracing are beautifully exemplified within the district mapped, in the deep lobe-shaped curve of the river just before it enters the sea. The terraces have been added one after another to the point of the lobe of land thus surrounded, which is known as Öen.

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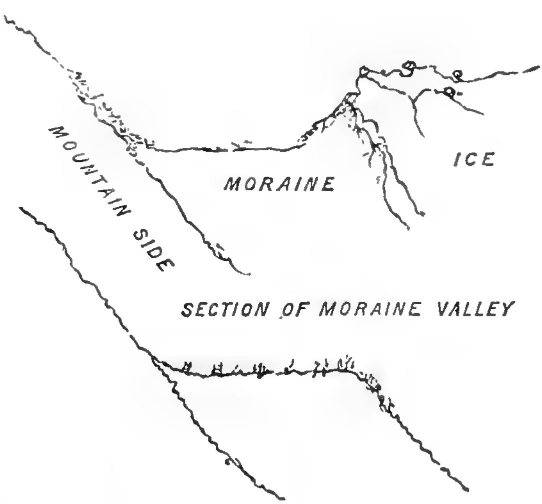
9. *The Parallel Roads of Lochaber.* By JAMES MELVIN.

These singular-looking lines, resembling in the distance water-races or roads traced along the mountain sides of three glens in Lochaber, have hitherto proved a puzzle to the learned and unlearned.

The theories submitted to account for their origin are open to grave objections, and all of them, save that of their being the margins of lakes held in by the ice of glaciers which flowed down the corries from the lofty mountains, have generally been given up.

This last, when carefully considered and looked at from different points of view in the district itself, seems open to serious objections. In the first place, it necessitates the existence of great glaciers in the lower portions of the glens with the water of lakes in the higher. It further necessitates the cessation of certain of these glaciers in Glen Spean, over perhaps nine-tenths of the district formerly producing them, and their retention in one-ninth of the surface from which they had previously flowed.

TASMAN VALLEY, MOUNT COOK, NEW ZEALAND.



SECTION AND TERRACE IN LOWER VALLEY.

(Method by which the Glacier forms Terraces somewhat similar, perhaps exactly similar, to those of the Lower Tasman Valley.—Page 200, Green's 'High Alps of Queensland.')

Those corries and opener glens, such as the Gulbein, the Treig, and the Laire which it is said supplied the ice-barriers when the upper roads in Glen Roy were being formed, issuing as they do from 100 square miles of mountain country, the peaks of which rise to 3,658 feet, according to the requirements of the ice-dam supporters, must become barren. These glaciers must shrink up, without any other reason being assigned than the necessity of their doing so to enable the supporters of the ice-dam to prove their case.

While this large extent of previously ice-producing country ceases to furnish any more ice to the Spean valley, one solitary glen, the Cour, drawing a supply from about eleven square miles, is allowed to maintain all its original ice-producing

power, and to form the great dam stretching more than four miles across the valley of the Spean, though aided on the other side of the Caledonian Canal by the ice from the glen.

The country which fed this glacier of the Cour consists of about eleven square miles of surface, with a peak 4,000 feet high. It does not seem to possess such a position so that a great glacier should continue to flow from it when the other glens adjoining had lost their glacier-producing power.

The drainage outlet of 700 miles of mountainous country within which the roads are is at Corron Ferry. It is narrow, contracted, and the ice would be jammed back during the intense period of glaciation, and a portion forced over the Col in Glen Spean into the Spey.

The roads consist of the usual glacial stuff from the hill sides. Neither sea shore nor lake shingle shells, water sorted sands nor silts, are met with. Some material run from the hill sides before vegetation covered the surface may be seen.

What, then, were the causes which led to the formation of those roads? The resting of the ice of the glaciers at certain levels after the great glaciation ceased, and when the ice in these glens of Gloy, Roy, and Spean found its way outward by the lowest level. The lateral moraines so formed when the supply of ice was sufficient to maintain their movement seaward are now the roads.

Thus, in Glen Gloy, No. 1, the road and several somewhat similar terraces, as shown in Sir Henry James Vance's work on the roads, would be formed by the ice after it had ceased to flow over the *col* into Glen Roy.

No. 2, in Glen Roy, after the ice ceased to flow into the Spey.

No. 3, after no more ice flowed into Glen Spean from Glen Roy, by the *col* Glen Glaister; also several other shelves or terraces seen in the district.

And No. 4, in Glens Roy and Spean, would be forming so long as the Gulbein, the Treig, the Laire, and the Cour supplied sufficient quantity of ice to maintain the glaciers in these valleys at the levels where the roads now are.

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10. *Further Evidence of the Extension of the Ice in the North Sea during the Glacial Period. By* B. N. PEACH, *F.R.S.E.*, *and* J. HORNE, *F.R.S.E.*

The authors briefly summarised at the outset the results of their investigations regarding the glacial phenomena of Shetland and Orkney, which point to the conclusion that they were glaciated by land ice that moved from the North Sea towards the Atlantic, while at a later period they were subjected to a purely local glaciation.

They then proceeded to call attention to certain observations of Dr. Traill, on the glacial phenomena of North Ronaldshay, which is situated at the extreme north-east corner of the Orcadian group, and, like the other isles, is composed of Old Red Sandstone and mainly of the characteristic flagstone series. In the red boulder clay an assemblage of stones foreign to Orkney was obtained, consisting of diorite, gabbro, granite with various kinds of metamorphic foliated rocks, volcanic tuff like that of the Ochils, chalk and chalk flints. With few exceptions these foreign blocks might have been derived from the basin of the Moray Firth and the surrounding high ground. Numerous smoothed and striated fragments of marine shells were also met with in the boulder clay. These phenomena are identical with those found in the boulder clay of the other Orcadian islands, and they point to the conclusion that the northern limits of Orkney must have been glaciated by ice from Scotland moving in a westerly direction.

Reference was also made to the results obtained by Dr. John Murray while exploring the 'Wyville Thomson Ridge,' in the summers of 1880 and 1882, the surface of which seems to be covered with boulder clay or moraine matter. The stones dredged from the northern part of the ridge consist of metamorphic rocks and Old Red Sandstone, which might have been derived from Shetland, while more than half of the blocks from the south end are composed of flagstones of the Orkney and Caithness flagstone series. From the distribution of the boulders, some of which are well striated, it is evident that the ice must have moved west-

wards across the submerged platform of which Shetland and Orkney are the surviving relics.

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11. *Recent Advances in West Lothian Geology.*[1] *By* H. M. Cadell, *B.Sc.*

Until after the discovery of the oil shales about twenty-five years ago, the relations of the Lower Carboniferous rocks of West Lothian were very imperfectly understood. Nothing of importance has been written on the geology of the eastern part of the county since 1861, when the Explanatory Memoir accompanying the Geological Survey map of the district was published. Since then much new evidence relating to the upper part of the Calciferous Sandstone series has accumulated.

The Calciferous Sandstone or Lower Carboniferous series, as developed along the great anticline of Midlothian, consists at the base of a series of red sandstones with thin shales and marls, and occasional interbedded volcanic rocks at the top. Above the red rocks come the white and gray sandstones of Granton and Craigleith, which are in turn overlain by the black shales of Wardie, and the sandstones and shales of Hailes and Redhall. Each of these two great divisions has, according to the measurements of Mr. John Henderson, a thickness of over 3,000 feet.

The oil shale group, which comes next, includes the 'Cement stone group,' apparently begins with the Pumpherston shale, situated some 780 feet below the Burdiehouse limestone. It occupies the remainder of the Calciferous Sandstone series and has in West Lothian a thickness of about 3,100 feet, so that the whole thickness of Lower Carboniferous rocks in West Lothian probably exceeds 9,000 feet. The Dunnet shale is the lowest member of the upper group of oil shales, and lies about 400 feet above the Burdiehouse or Camps limestone. About 450 feet higher up comes the Broxburn shale, which is perhaps the most important of the West Lothian oil shales. The strata intervening between the Dunnet and Pumpherston shales, and including the limestone, are chiefly argillaceous shales with thin calcareous bands and occasional sandstones. Above the Dunnet shale they become more arenaceous, and thick sandstone beds are developed, one of which has long been quarried at Binny, near Uphall, for building and ornamental purposes. The Broxburn shale, which is several fathoms above the Binny sandstone, forms a well-marked horizon, as it underlies a group of marls and thin limestone bands varying in thickness from 80 to 270 feet. This calcareous zone, locally known as the 'Broxburn Marl,' passes under the Fells shale, above which comes another series of sandstone beds about 240 feet thick, which underlie the Houston coal. This is perhaps the oldest coal seam in Britain, as in the Broxburn district it is situated about 1,000 feet below the base of the Carboniferous Limestone series. The Houston coal is covered by about 200 feet of pale green and red amorphous marl, sometimes containing pieces of volcanic ash, and is apparently a fine volcanic mudstone. A thin coal seam and some oil shale occur just above the 'Houston marl,' and two other oil shales have been worked still higher up, the highest of which—the Raeburn's shale—is some 400 feet below the Carboniferous limestone.

The oil shales and underlying parts of the Calciferous Sandstone series have no regular strike, but are bent about into troughs, domes, and anticlines, and are dislocated by large faults, besides which there is great irregularity in the thickness and character of the rocks, so that to work out the geological structure of the ground without the aid of mining information would be an impossible task.

The oil shales are simply fine clay shales impregnated with hydrocarbon, and when distilled yield on an average 30 gallons of crude oil per ton, and enough ammonia to yield from 10 to 45 lbs. ammonia sulphate. They have evidently been deposited extremely slowly in a large gradually-subsiding estuarine or fresh water area, inhabited by numerous fishes, lamellibranchs, and small crustaceans, whose remains, along with those of plants, were constantly being deposited on the sea

[1] Communicated by permission of the Director-General of the Geological Survey.

floor along with a comparatively small proportion of muddy sediment. Oil shale is easily recognised in the field by its resistance to the disintegrating action of the weather, and by the facility with which it can be cut and curled up with the point of a knife.

The Carboniferous Limestone series, whose thickness is about 2,000 feet, is divisible into three main groups: a basal group with sandstone shales, thin limestones, and one coal seam at the bottom; a central group with coal seams and no limestones; and an upper group with three limestones, sandstones, and a few thin coal seams. At Bo'ness, on the Firth of Forth, north of Linlithgow, the coal-bearing group has a thickness of about 900 feet, and is subdivided by a central zone of interbedded basalt rocks 330 feet in thickness, into an upper and a lower series, each containing four workable seams of coal and a seam of ironstone.

The oldest member of the interesting volcanic series of West Lothian seems to be a bed of tuff resting on the Houston coal near Queensferry, from the denudation of which the Houston marl here situated a few fathoms higher up, may have been derived. Volcanic activity was rife during almost the whole of the Carboniferous limestone period, especially in the district south of Linlithgow, where the great bank of interbedded basalt rocks forming the Bathgate and Torphichen Hills was poured forth. These old lavas extend from beneath the lowest marine limestone in almost uninterrupted succession to near the top of the limestone series, and have a total thickness of more than 2,000 feet. On each side the volcanic rocks thin out and become replaced by sedimentary strata and coal seams in the Bo'ness and Bathgate coalfields. 'Necks' of diabase and basalt tuff, piercing the lower parts of the Carboniferous Limestone and the Calciferous Sandstone strata to the east of Linlithgow are numerous, and have probably been connected with interbedded rocks on higher horizons now removed by denudation. The largest, forming the Tor Hill at Ecclesmachan, has a major diameter of about 600 yards, and cuts through the Houston coal and underlying shales.

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12. *Barium Sulphate as a Cementing Material in Sandstone.* *By* Professor Frank Clowes, *D.Sc.*

Bischof mentions instances of foreign sandstones in which the material which cements the sand grains together is barium sulphate; but it appears that up to the present time no such sandstone has been discovered in the United Kingdom. Having learned from my colleague, Professor Blake, that opinions of geologists differ regarding the calcareous nature of certain sandstone beds in the neighbourhood of Nottingham, I undertook to ascertain the chemical composition of this sandstone. At the spot in question the sandstone appears as two conical hills known as Stapleford and Bramcote Hills, and as a pillar of rock about twenty feet in height known as the Hemlock Stone. The Hemlock Stone stands in the space intervening between the hills, and is capped so as to be somewhat mushroom shaped. In company with Professor Blake I procured specimens of the sandstone at different levels of the hills and of the stone. One of the specimens was subjected to careful chemical analysis by two senior students in my laboratory at the University College, Nottingham; they find the very high amount of 30 per cent. of barium sulphate in the sandstone. I have also recently detected the presence of much barium sulphate in all the sandstone specimens from both the hills and the Hemlock Stone, while some of the lower beds also contain calcium carbonate. The percentage proportion of barium sulphate present in the samples is at present being determined with care.

The results of the chemical examination of this sandstone thus far show that geologists who took samples from the lower part of the Hemlock Stone would consider the sandstone to be calcareous after applying the usual acid test, whilst others who examined the cap of the stone would find no calcareous matter, and would fail to detect the barium sulphate which is the true cementing material. It seems probable that the protective cap of the pillar owes its comparative permanence against weathering action to the presence of this almost insoluble sulphate in large proportions.

In some of the sandstones which have been examined the barium sulphate is very unequally distributed, forming either a network or a series of small patches more or less spherical in shape. In such sandstone the sand grains which are uncemented by the sulphate are loose and readily separated from one another. Hence, when subjected to weathering, it presents a honeycombed or mammillated appearance. In one bed which caps the Bramcote Hill, and which is usually described as the pebble bed, the removal of the intervening loose sand leaves little cemented masses about the size of a hazel-nut: these, however, are not pebbles in the ordinary sense of the word, but are merely sand grains cemented by the sulphate.

I have attempted to trace some evidence of the way in which the barium sulphate has been introduced into the sand bed. It may have been deposited originally with the sand grains; but if this is its origin it has undergone physical change, since it now presents a compact crystallised mass. It seems certain, therefore, that it has either been originally deposited from solution, or has been rendered crystalline by the slow percolation of a solvent liquid through the sedimentary deposit. A third method seems possible. Bischof carried out experimentally the conversion of barium carbonate into sulphate by the action upon it of calcium sulphate solution; this double decomposition would produce barium sulphate together with calcium carbonate, and precisely such a mixture is found in the lower beds of the Hemlock Stone.

As regards the possibility of barium sulphate existing in solution, as was supposed in an earlier part of this communication, I have recently examined a stalactite which consists almost wholly of barium sulphate; and specimens of little sand masses bound together by barium sulphate in large crystals have also come into my hands. A solvent has in any case been present at some time, to cause the barium sulphate of these sandstones to assume the crystalline condition, since Bischof shows that the sulphate cannot be crystallised by fusion.

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13. *Notes on Fuller's Earth and its applications.* *By* A. C. G. Cameron.

The author in this paper describes Fuller's earth, its properties, and varieties. In its more concrete signification Fuller's earth is the name applied to the red loamy stratum overlying the Inferior Oolite in the south of England. But its more general application is of economic and not of geological significance. He mentions that that dug from near the base of the Bedfordshire Greensand is of superior quality, and characterises it as a purifier of water. Fuller's earth in general is mentioned as a fine clay, less used now than formerly for cloth dressing. Considerable quantities are, however, still dug from the Lower Greensand and Oolites of the south of England for fulling and general cleansing purposes. Aspley Heath, on the brow of the Greensand escarpment, Woburn, Bedfordshire, is described as the locality where operations are presently going on for the purpose of procuring varieties of Fuller's earth. Cylindrical holes, called 'earth wells,' are dug deep in the soft yellow sands, sometimes rocky with ferruginous lumps and thin carstone, in order to reach the Fuller's earth, which lies far down as a tabular and nearly horizontal mass, separated by not many feet of sand from the Oxford clay. Nearly two hundred years ago the pits were at Wavendon, an outlier of the Greensand, amongst the Oxford clay. A description of the beds is given as presently existing. Although superficially considered as all one earth, the substance is of three distinct kinds, which are mentioned, and their local names given. Allusions are made to substances dug in Warwickshire, the Isle of Skye, and Maxton Roxburghshire, as substitutes for Fuller's earth, and a letter is quoted from a resident in Maxton bearing on this subject. The action of Fuller's earth on peaty or otherwise discoloured water is described, with special allusion to, and description of, the 'Natural Mineral Water' at Flitwick, Bedfordshire. Conflicting opinions as to this mineral water are given, with analysis supplied by Drs. Piesse and Johnstone, public analysts, London, and one published by a Professor White. Results of various experiments are stated, showing the efficacy of Bedfordshire Fuller's earth as a filtering medium. The author is not prepared to say whether these filtra-

tions are mechanical, or are due partly to chemical action, as this question is still undetermined. He suggests that Fuller's earth might be advantageously placed with other materials in filter beds, or otherwise used as a water purifier on a large scale.

WEDNESDAY, SEPTEMBER 16.

The following Papers and Report were read:—

1. *On the Glacial Deposits at Montrose.* *By* Dr. HOWDEN.

These consist in order of age, first, of the non-fossiliferous boulder clay, derived chiefly from the denudation of the great conglomerate. Second, a glacial marine clay, containing the remains of the Arctic seal (*Phœa hirta*), Arctic birds, fishes, star-fishes, mollusca, and foraminifera, besides pieces of ice borne chalk, flint, coal, and other rocks foreign to the district. Third, deposits of peat, in which are found remains of the reindeer, trees, and bog plants, including the buckbean; a grain of the common barley was also got in this peat. Fourth, a thick bed of estuary, or scrobicularia silt, containing shells of species found living in the present estuary basin of the South Esk. In this deposit at the Redfield Railway cutting, nine feet below the surface, the skull of an ox, *Bos longifrons*, was found beneath an undisturbed deposit of sand and coarse clay. Fifth, a bed of apparently glacial coarse clay. These deposits terminate on a great ridge or storm beach consisting of pebbles and small boulders derived from the boulder clay. This ridge divides the town of Montrose into two halves, known to builders as the clay half and the sand half. In the sand half, slightly above the level of the present sea beach, marine shells are found of species now living on the coast, but a much larger size. The diagrams and specimens exhibited indicated repeated alternation of climate and level since the earlier glacial period.

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2. *Notes on the Rocks of St. Kilda.* *By* ALEXANDER ROSS, *F.G.S.*

On a visit to St. Kilda in 1884 I collected a few specimens of the rocks of which the island is composed, and which are now presented for inspection to the members of the British Association.

The island has been described as being in the form of the letter H, the northern limb being represented by Connacher and Oschival, and the southern by the Mullach More. These limbs are connected by a ridge which forms the cross bar of the H, and divides the north from the south bay. The latter bay is nearly circular, the hills sloping in all directions and forming an almost perfect amphitheatre.

The land rises to a considerable height on the west side of the island, which is bounded by cliffs from 800 to 1,000 feet high.

The island is composed of granite and gabbros, which meet in a line running from the west side of the village at the south bay to the centre of the glen at north bay. The portion to the north of this line is composed entirely of cream-coloured granite, while that to the south consists of greenstones and gabbros.

In the course of a walk extending from the landing-place on the north side, along the summit of Oschival and Connacher down into the valley at north bay, and along the north shoulder of Mullach More back to the south bay, I picked up the specimens now exhibited.

Passing along the top of the ridge between Oschival and Connacher and over the top of the latter, I found as I began to descend towards the line of junction the granites becoming finer grained and more compact. Along the line of junction the change is very marked, and on crossing it, we come on the gabbros and greenstones, on the southern side of the glen. Some of the specimens illustrate this walk.

Specimens were also taken from the bare slopes and precipices near the sea, where the junction can be more clearly seen.

The specimens picked up along the line of junction consisted of granite studded throughout with angular fragments of basalt, which fact appears to indicate the posteriority of the granite.

Taken by themselves these specimens would seem to point to the conclusion that the granite had been erupted at a later date than the gabbros, and that the molten granite had included the shattered fragments of an older rock in it.

The main question which the specimens would appear to suggest is—'What are the respective ages of the granites and gabbros?'

The specimens in my opinion appear to point to the posteriority of the granite, and one specimen shows a vein of granite piercing the basalt.

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3. *Eleventh Report on the Circulation of Underground Waters in the Permeable Formations of England and Wales, and the Quantity and Character of the Water supplied to various Towns and Districts from these Formations.*—See Reports, p. 380.

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4. *On Deep Borings at Chatham: a Contribution to the Deep-seated Geology of the London Basin. By* W. WHITAKER, *B.A., F.G.S., Assoc.Inst.C.E.*

A few years ago the Admiralty made a boring in the Chatham Dockyard Extension, to the depth of 903½ feet, just reaching the Lower Greensand, and in 1883-84 followed this by another boring, near by, to increase the supply, which has led to an unexpected result. After passing through 27 feet of Alluvium and Tertiary beds, 682 of Chalk, and 193 of Gault, the Lower Greensand was again reached; but, on continuing the boring, was found to be only 41 feet thick, when it was succeeded by a stiff clay, which, from its fossils, is found to be Oxford Clay, a formation not before known to occur in Kent.

At its outcrop, about seven miles to the south, the Lower Greensand is 200 feet thick, and is succeeded, a little further south, by the Weald Clay, there 600 feet thick. Not only, however, has this 600 feet of clay wholly disappeared, but also the whole of the next underlying set of deposits, the Hastings Beds, which crop out everywhere from beneath the Weald Clay, and are also some hundreds of feet thick.

More than this, the Purbeck Beds, which underlie the Hastings Beds near Battle, are absent, and also the Portlandian, Kimmeridge Clay, Corallian, &c., beds which have been proved above Oxford Clay in the Subwealden Boring, to the great thickness of over 1,600 feet.

We are therefore faced with a great northerly thinning of the beds below the Gault, a fact agreeing in the main with the evidence given of late years by various deep wells in and near London.

Three other deep borings have been made or are being made near Chatham, all of which have passed through the Chalk into the Gault, and one has gained a supply from the sand beneath.

The practical bearing of the Chatham section is, however, to enforce the danger of counting on getting large supplies of water in the London Basin from the Lower Greensand, by means of deep borings at any great distance from its outcrop.

Even if Lower Greensand occur at all in such places, it will probably be in reduced thickness, and therefore with reduced water-capacity.

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5. *On the Waterworks at Goldstone Road, Brighton. By* W. WHITAKER, *B.A., F.G.S., Assoc.Inst.C.E.*

Notes of a visit underground in December 1884, when the water was pumped down for extending the galleries.

These works are perhaps the best example of the right way of getting a very

large supply of water from the Chalk, galleries being driven (in one case to the length of 800 feet) at about low-water level, so as to cut the fissures and intercept the water on its way to the sea.

The whole of the works (shafts and galleries) are in the White Chalk, with but few flints in the bedding-planes, but with many oblique layers along joint-planes. The supply comes chiefly from a few powerful springs, and, though small contributions issue between these, it is noteworthy how far a tunnel has sometimes been driven before reaching a fissure of large yield. Under these circumstances borings, or even shafts, might have failed to yield a large supply.

The roof of the north-eastern gallery is throughout of one bed, rarely needing support, a thin brittle layer of flint at its base being cleared away.

Section D.—BIOLOGY.

President of the Section—Professor W. C. McIntosh, M.D., LL.D., F.R.S.L. & E., F.L.S.

THURSDAY, SEPTEMBER 10.

The President delivered the following Address:—

I have selected the subject of the phosphorescence of marine animals for a few remarks on the present occasion—the theme, perhaps, being the more appropriate from its congenial local surroundings; for, like St. Andrews, Aberdeen is an

'old University town
Looking out on the cold North sea.'

A phenomenon so striking as the emission of light by marine organisms could not fail to have attracted notice from very early times, both in the case of navigators and those who gave their attention in a more systematic manner to the study of nature. Accordingly we find that the literature of the subject is both varied and extensive—so much so, indeed, that it is impossible on the present occasion to give more than a very brief outline of its leading features. This is a subject of less moment, however, since the great microscopist, Ehrenberg, in his treatise, 'Das Leuchten des Meeres,' published by the Berlin Academy in 1835, has given a very full account of the early literature on phosphorescence, both in marine and terrestrial animals, no less than 436 authors being quoted. The limitation just mentioned is therefore sufficiently warranted.

Though it is in the warmer seas of the globe that phosphorescence is observed in its most remarkable forms—as for instance the sheets of white light caused by *Noctiluca*, and the vividly luminous bars of *Pyrosoma*—yet it is a feature which the British zoologist need not leave his native waters to see both in beauty and perfection. Many luminous animals occur between tide-marks, and even the stunted seaweeds near the line of high-water everywhere sparkle with a multitude of brilliant points. As a ship or boat passes through the calm surface of the sea in summer and autumn, the wavelets gleam with phosphorescent points, or are crested with light; while the observer, leaning over the stern, can watch the long trail of luminous water behind the ship, from the brightly sparkling and seething mass at the screw to the faint glimmer in the distance. On the southern and western shores, again, every stroke of the oar causes a luminous eddy, and some of the smaller forms are lifted by the blade and scintillate brightly as they roll into the water. The dredge and trawl likewise produce, both in the shallower and deeper parts of our seas, many luminous types of great interest and beauty.

I shall, in the first instance, glance at the various groups of marine animals which possess the property of phosphorescence, and thereafter make some general remarks on the subject. It is found then that this feature is possessed by certain members of the Protozoa, and by the following groups of the Metazoa, viz.: Cœlenterates, Echinoderms, Worms, Rotifers, Crustaceans, Molluscoids, Mollusks, and Fishes.

About the middle of last century Baster found that at least three species of

what he called microscopic animalcula,[1] apparently Infusoria, were phosphorescent; and fully half a century later Pfaff noticed that the luminosity of the sea at Kiel was due to certain members of the group just mentioned. Subsequently both Michaelis and Ehrenberg met with phosphorescent Infusoria in the Baltic, the latter describing them as species of *Peridinium* (now *Ceratium*), and *Prorocentrum*. The same fact, associated with the absence of *Noctiluca* at Kiel, has again more recently been brought forward by Stein. In our own seas I have been especially struck with this feature in July and August, the whole surface of the sea along the eastern shores of England and Scotland teeming with *Ceratium* and *Peridinium*, besides other Infusoria, which form a greenish scum on the interior of tow-nets in inshore water, and for many miles seaward. As the waves curl from the sides of the boat in quiet water, the crest of each sparkles with multitudes of luminous points, which gleam for a moment as the ripple stretches outward and then disappear; or still more vividly when the plunging vessel sends the sparkling spray all around the bow. If on removing the tow-net from such water at night it is suddenly jerked, the whole interior is beautifully lit up with a luminous lining, which glows brightly for a few seconds and then fades. I have been unable, nevertheless, to satisfy myself as to the phosphorescence of isolated examples of *Ceratium*, and Mr. Murray (who is inclined to follow Klebs in considering them Algæ) tells me that he has not been more successful.

The most conspicuous member of the first group (viz., the Protozoa), however, is *Noctiluca*, which for a long time has been associated with luminosity in many seas. The minute size of this little transparent gelatinous sphere, which ranges from $\frac{1}{5}$ to $\frac{1}{3}$ of a millimètre, probably gave origin to some of the ancient views that the phosphorescence of the sea originated from the water, and not from any visible organisms. Amongst the first who clearly made known the relationship of this minute body to the phenomenon we are examining, was M. Rigaut, a French naval surgeon, who examined it off various parts of the French coast as well as off the Antilles, and pointed out in a memoir communicated to the Academy, that the luminosity of the sea was caused by an immense number of what he termed little spherical polyps, about a quarter of a line in diameter.[2] The observations of this acute French surgeon were followed up by many subsequent authors, amongst whom may be mentioned Baker, Martin Slabber, Abbé Dicquemare, Suriray, Macartney, and Baird; while in more recent times Verhaege, De Quatrefages, and Giglioli have specially studied the phosphorescence of the sea caused by *Noctiluca*. The light given out by this form is occasionally spread over a large area, and is often evident along the margin of the beach, where the broad belts of Noctilucæ gleam in the broken water. It is not uncommon in summer on the southern shores of Britain, while it is rare in the northern; but it stretches into most of the great oceans, and is the cause of that diffused and silvery phosphorescence so well known to voyagers in the warmer seas. At Ostend, Verhaege found the maximum number in a given quantity of water in the warm months, few or none appearing in the winter. The observations of De Quatrefages [3] were made on the shores of France as well as those of Sicily, for he accompanied the distinguished Professor Henri Milne-Edwards (whose loss science has had so recently to deplore) on his celebrated 'Voyage en Sicile,' and they were more extensive than those of the previous author. He attributes the emission of the clear bluish light in quiet water, or the white light with greenish or bluish touches in broken water, to any physical agent which produces contraction, the scintillations arising from the rupture and rapid contraction of the protoplasmic filaments in the interior. Thus, like Verhaege and others, he found no special luminous organ. Moreover, Ehrenberg and De Quatrefages observed that the light emitted by *Noctiluca*, though apparently uniform under a lens, was broken up into a number of minute scintillations when highly magnified. Mr. Sorby, in examining the light of this form,

[1] *Opuscula Subseciva*, vol. i. p. 31. tab. iv. fig. 1.

[2] *Journal des Savants*, tom. xliii. Feb. 1770, pp. 554–561.

[3] 'Observations sur les Noctiluques,' *Ann. des sc. nat.* 3e Série, Zool., tom. xiv. p. 226.

has been unable to obtain satisfactory spectroscopic results, apparently from its feebleness.

Besides *Noctiluca*, which was chiefly met with in inshore water, Mr. Murray, of the 'Challenger,' describes various species of *Pyrocystis*,[1] a closely allied form, and indeed some of which have been thought to be identical with the former. They abound in the open sea, and are the chief causes of its phosphorescence in the tropical and subtropical oceans. The light is stated to proceed from the nucleus, and in this respect it diverges from that observed by De Quatrefages in *Noctiluca*. When shaken in a glass, they give out, Sir Wyville Thomson observes,[2] the uniform soft light of an illuminated ground-glass globe.

Dr. Giglioli, during the voyage of the Italian frigate 'Magenta,' mentions[3] that another division of the Protozoa, viz., the Radiolaria, show phosphorescent properties. In the Pacific the genera *Thalassicolla, Collozoum,* and *Sphærozoum,* shone with an intermittent greenish light. It is possible that Dr. Baird,[4] in his earlier paper, refers to the same group when describing an unknown phosphorescent pelagic organism.

No group of marine animals is more prominent in regard to phosphorescence than the Cælenterates. The Hydroida are familiar examples,[5] and, as Mr. Hincks observes, none excels the common *Obelia geniculata,* which forms pigmy forests on the broad blades of Laminariæ all round our shores. In the fresh specimen a touch during summer causes a large number of luminous points to appear on the zoophytes, the stems most irritated emitting beautiful flashes, which glitter like faintly-dotted lines of fire, the points not being harshly separated, but blending into each other, while the shock imparted by the instrument detaches the minute medusoids, which scintillate upward from the parent stem to the summit of the water. Mere blowing on the surface in July, where Laminariæ abound, suffices to produce the emission of light from the pelagic buds. Moreover, these minute bodies, along with the various species of *Ceratium* and minute larval forms of diverse kinds, are sometimes swept by the gales landward, and cause phosphorescence where least expected. In the same manner Vaughan Thompson[6] found luminous patches on the masts and windward yard-arms on board ship, and they gradually mounted upward as the gale increased. Many of the free gonosomes of the Hydroids are as luminous as the polypites, and indeed have been described by some of the older naturalists as one of the main causes of the luminosity of the ocean. The light in these (e.g., *Thaumantias*) gleams round the margin and along the four radii.

The Ascraspedote Medusæ have also been signalised as factors in producing the phosphorescence of the sea, such forms as *Pelagia noctiluca* and *Pelagia cyanella* being especially prominent. Spallanzani, indeed, made an elaborate series of experiments on the luminosity of the Medusæ in his voyage to the Two Sicilies. Some of these, as *Dactylometra* (*Pelagia*) *quinquecirra,* Agassiz, are nocturnal in their habits. They are only occasionally found floating at the surface during the day, while at night, in the same localities, the bottom swarms with these large masses of dull phosphorescence, moving about with the greatest rapidity.[7] Species of *Rhizostoma* were likewise observed by Giglioli to have a pale bluish luminosity. The two most abundant Medusæ of our eastern shores, viz., *Aurelia aurita* and *Cyanea capillata* (both in its young purple and adult brown condition), so far as I can make out, exhibit no luminosity. This agrees with the views expressed long ago by Ehrenberg.

The oceanic Hydrozoa (*Siphonophora*) are likewise characterised by their

[1] *Proc. Roy. Soc.* vol. xxiv. p. 553, pl. xxi.; and *Narrative*, Zool., vols. i., and ii. p. 935–38.

[2] *Atlantic*, vol. ii. p. 87.

[3] *Atti della R. Accad. delle Sc. di Torino*, vol. v. 1869–70, p. 492.

[4] *Loudon's Mag. Nat. Hist.* vol. iii. p. 312, fig. 81, *c, d*.

[5] Even after many days and in impure water some of these retain this property, a shock to the stem sending off a crowd of luminous points from the trophosome.

[6] *Zoological Researches*, vol. i. part i. mem. iii. p. 48. 1829.

[7] Agassiz, *North American Acalephæ*, p. 49. Cambridge, 1865.

phosphorescence. Thus Giglioli met with luminosity in *Abyla, Diphyes, Eudoxia, Praya* and *Aglaismoides*. Dr. Bennett [1] has also observed luminosity amongst the Coralligenous Actinozoa; the grazing of a boat on a coral reef causing a vivid stream of phosphoric light. Similar observations were made on Madrepores by Giglioli,[2] the light in this case being bright greenish and enduring some minutes.

Amongst the Alcyonarians the luminosity of the common Sea-Pen (*Pennatula phosphorea*) has been long known, and was studied by Gesner, Bartholin, Adler, and others. In the earlier part of this century Grant gave the oft-quoted description,[3] in which he pictures a *Pennatula* 'with all its delicate transparent polypi expanded and emitting their usual brilliant phosphorescent light, sailing through the still and dark abysses by the regular and synchronous pulsations of the minute fringed arms of the whole polypi.' But it ought to be balanced by his concluding statement, that the sea-pens are probably stationary, or 'lie at the bottom, and move languidly like Spatangi, Asteriæ or Actiniæ.' [4] Edward Forbes again observed that the light proceeded from the irritated point to the extremity of the polypiferous portion, and never in the opposite direction. As Dr. George Johnston tells us, Forbes induced Dr. George Wilson to test, along with Professor Swan, the polyps during phosphorescence by a delicate galvanometer, but without result. He thought the luminosity was due to a spontaneously inflammable substance.

More recently a series of interesting observations were made by Panceri on the structure and physiology of the luminous organs of this form. His conclusions are (1) that the light emanates from the polyps and zoids; (2) that the phosphorescent organs are the eight white cords adhering to the outer surface of the stomach, and that these are chiefly composed of cells containing a substance of a fatty nature, the oxidation of which causes the light. Panceri's conclusions further considerably modify Forbes's views about the direction of the waves or points of light. He supposes that the elements which stand in the place of nerves are capable of producing in the luminous batteries of the polyps a momentary oxidation—more rapid and more intense—accompanied by phosphorescence. Like those examined by Professor Milnes Marshall,[5] the specimens at St. Andrews, after irritation, show a series of brilliant coruscations which flash along the rows of polyps in a somewhat irregular manner.

Two other Alcyonarians, *Funiculina* and *Umbellularia*, are equally phosphorescent. Though the former is familiar enough to some of the long liners of the outer Hebrides and west coast, it is rare that either is procured for scientific investigation. *Funiculina quadrangularis*, according to Forbes,[6] gives out a vivid bluish light, which comes from the bases of the polyps, and appears to be connected with the reproductive system. Sir Wyville Thomson [7] describes the specimens procured in the 'Porcupine' as resplendent with a steady pale lilac phosphorescence like the flame of cyanogen; and always sufficiently bright to make every portion of a stem caught in the tangles distinctly visible. The same zoologist mentions that the stem and polyps of *Umbellularia* are so brightly phosphorescent, that Captain Maclear found it easy to determine the character of the light by the spectroscope. It gave a restricted spectrum sharply included between the lines *b* and D.[8]

Besides the foregoing Alcyonarians, *Isis* and *Gorgonia* have been indicated as likewise phosphorescent. Dr. Merle Norman and Dr. Gwyn Jeffreys (whose death since the last meeting of the British Association is a serious loss to science) mention a beautifully luminous *Isis* on board the French ship 'Le Travailleur'; and Sir Wyville Thomson,[9] with the facile and genial pen which characterised the

[1] *Gatherings of a Naturalist*, p. 69. 1860.

[2] *Atti della R. Accad. d. Sc. di Torino*, vol. v. p. 502.

[3] *Brewster's Edin. Journ.* vol. vii. p. 330. 1827.

[4] Certainly the specimens in the St. Andrews Marine Laboratory were very helpless.

[5] *Report on the Oban Pennatulidæ*, p. 49. Birmingham, 1882.

[6] Johnston's *Brit. Zooph.* vol. i. p. 166.

[7] *Depths of the Sea*, p. 149.

[8] *Atlantic*, vol. i. p. 151.

[9] *Ibid.* vol. i. p. 119.

lamented naturalist, gives a fascinating picture of a long, delicate, simple Gorgonian which came up in immense numbers in the trawl from 600 fathoms off the Spanish coast. He conjures up this Gorgonian forest as an animated cornfield waving gently in the slow tidal current, and glowing with a soft diffused phosphorescence, scintillating and sparkling on the slightest touch, and now and again breaking into long avenues of vivid light, indicating the paths of fishes or other wandering denizens of these enchanted regions. Professor Moseley thinks that this brilliant phosphorescence of the Alcyonarians may be regarded as an accidental production, but that it may be of occasional service. Further, that the deep sea is at any rate lighted up by these Alcyonarians, which would thus form luminous oases round which animals with eyes might possibly congregate.[1]

The last group of the Cœlenterates, the *Ctenophora*, are even more conspicuous than the foregoing in regard to luminosity. It is indeed long since the Abbé Dicquemare descanted on *Cydippe* (*Pleurobrachia*) and Suriray on *Beroë*, while subsequent authors have made it clear that the majority of this group are phosphorescent. In our own seas, as Professor Allman observes, *Beroë* at various stages is one of the most prominent luminous forms during certain seasons. Their enormous numbers make their effects more striking, though the intensity of the phosphorescence is less than that of the Medusæ. Quiet seas like Bressay Sound and the Firth of Forth are occasionally covered by a dense layer of these animals. Professor Allman found that *Beroë* did not phosphoresce if suddenly taken from light into darkness, but that after they had remained about twenty minutes in obscurity they became luminous. Considerable variety exists in this respect at St. Andrews, some emitting light at once, others showing none. It is probable that this uncertainty is connected with the hygienic condition of the individuals.

In foreign seas many brightly luminous species are met with. Thus Professor A. Agassiz[2] describes *Mnemiopsis Leidyi* as 'exceedingly phosphorescent, and when passing through shoals of these Medusæ, varying in size from a pin's head to several inches in length, the whole water becomes so brilliantly luminous that an oar dipped up to the handle can plainly be seen on dark nights by the light so produced; the seat of the phosphorescence is confined to the locomotive rows, and so exceedingly sensitive are they that the slightest shock is sufficient to make them plainly visible by the light emitted from the eight phosphorescent ambulacra.' The same author[3] mentions that *Lesueuria* has a very peculiar bluish light of an exceedingly pale steel colour, but very intense. Giglioli, again, found that the beautiful riband-like *Cestus* shone with a reddish yellow light, but in *Eucharis* the latter was intensely blue.[4]

While many of the preceding group are pelagic at all periods of their existence, the luminous star-fishes are in their adult condition members of the bottom fauna. The larval stages of the brittle-stars, however, are passed at the surface of the water, where it is probable they add their quota to swell the ranks of the phosphorescent types. Amongst the first to note this property in the brittle-stars was Professor Viviani, who found on the shores of Genoa a little brittle-star which he termed *Asterias noctiluca*,[5] and which probably is identical with the *Amphiura elegans* of Leach. Péron likewise mentions the phosphorescence of his *Ophiura phosphorea*. Sir Wyville Thomson observed in the 'Porcupine' that the light from *Ophiacantha spinulosa* was of a brilliant green, coruscating from the centre of the disk along the rays and illuminating the whole outline of the starfish.[6] More recently, Professor Panceri of Naples has re-examined the phosphorescence of the species described by Viviani, and he finds that though with the first momentary glow the whole ray is lit up with a greenish light, the luminous points corre-

[1] *Notes of a Naturalist on the 'Challenger,'* p. 590.

[2] *North American Acalephæ*, p. 20. Cambridge, 1865.

[3] *Op. cit.* p. 24.

[4] *Op. cit.* p. 495–96.

[5] *Phosphorescentia Maris*, Genoa, 1805, p. 5, tab. i. figs. 1–2. He observes: 'Speciem hanc radiatæ instar stellæ scintillas in marinis aquis excitasse, quas electrico fluido adscripserunt, admodum probabile est.'

[6] *Depths of the Sea*, p. 98.

spond with the bases of the pedicels and are ranged in pairs along the arms.[1] In deep water (between 20 and 40 fathoms) off our eastern shores, *Ophiothrix* gleams all over the trawl-net with a pale greenish light; but the adults of same form between tide marks give no trace of luminosity.

The older authors were familiar with certain luminous annelids which they termed *Nereides,* such as *Nereis phosphorans.* Ehrenberg paid considerable attention to this group, specially referring to *Polynoë fulgurans* from the North Sea, *Nereis noctiluca*[2] and *Nereis* (*Photocharis*) *cirrigera,* the latter species having a photogenic structure in its cirri like the electric organ of the Torpedo. This form is probably related to the ubiquitous *Eusyllis,* which, under various names, has been noticed by many observers. Thus very likely it is the same species that is mentioned by Harmer, in Baker's 'Employment for the Microscope,'[3] as having been found on oyster shells; and also by Vianelli, who describes it as a caterpillar-like form amongst seaweeds. Indeed the Syllideans have been conspicuous in the literature of phosphorescence from the time of De la Voie,[4] and Vianelli,[5] to the recent period of Claparède[6] and Panceri.[7] The structure of the cirri of the phosphorescent forms, however, gives no support to the opinion of Ehrenberg that they possess a special photogenic structure.

The luminous annelids group themselves under five families, viz., the Polynoidæ, Syllidæ, Chætopteridæ, Terebellidæ, and Tomopteridæ, and the number may yet be extended to include other pelagic types.

In the first family one of the most abundant is *Harmothoë imbricata,* which lives both between tide-marks and in deep water, and is cosmopolitan in geographical distribution. It discharges bright greenish scintillations from the point of attachment of each dorsal scale; and thus, under irritation, the flashes are arranged in pairs along the body, or in a double moniliform line. If severely pinched the worm wriggles through the water, emitting sparks of green light from the bases of the feet. The separated scales also continue to gleam for some time, chiefly at the surfaces of attachment (scars), near which, in each, a ganglion exists. The same phenomenon is readily produced in a fragment either of the anterior or posterior end of the body. No mucous secretion is emitted, but the light is clearly produced by the will of the animal, and by the agency of its nervous system. A recent writer, Dr. Jourdan,[8] has endeavoured to prove that this luminosity in another member of the Polynoidæ (viz., *Polynoë torquata*) is produced by cells secreting a phosphorescent mucus, but this view is by no means applicable in all cases.

Besides the species mentioned, various other forms in this family are equally luminous, such as *Polynoë scolopendrina, Achloë astericola, Polynoë lunulata,* and a Zetlandic *Eunoa.*

As an example of the Syllidæ, the common *Eusyllis,* so often mentioned by previous authors, may be taken. Under irritation a fine green light is emitted from the ventral aspect of each foot, and the scintillations seem to issue from many points at each space, flash along both sides of the worm posterior to the point of stimulation, and then disappear. Under severe irritation the animal remains luminous behind the injured part for nearly half a minute, while the surface of granular light on each segment is larger than usual, and in some instances those of opposite sides are connected on the ventral aspect by a few phosphorescent points. The body behind the irritated region has a paler pinkish hue immediately after the emission of light, showing that the luminosity is diffused.

In the Chætopteridæ the phosphorescence is remarkably beautiful, bright flashes being emitted from the posterior feet; but the most vivid luminosity is at a point on the dorsum between the lateral wings of the tenth segment. Here the abundant

[1] *Atti della R. Accad. d. Sc. Fisiche e Mathem. di Napoli,* 1875, p. 17, pl. iv. fig. 1–3.
[2] Supposed by some to refer to *Noctiluca miliaris.*
[3] Page 400.
[4] 1666, *fide Panceri.*
[5] *Nuove Scoperte intorno le Luci dell' Acqua Marina.* Venezia, 1749.
[6] *Glanures Zootomiques,* p. 95.
[7] *Op. cit.* p. 8.
[8] *Zoologischer Anzeiger,* 2 March, 1885, No. 189, p. 133.

mucus exuded by the animal can be drawn out as bluish-purple fire of great intensity, which, besides, now and then gleams along the edges of the wing-like processes, and illuminates the surrounding water. A very characteristic odour, somewhat resembling that produced by phosphorus in combustion, is given out by the animal during such experiments. In this connection it may be observed that Quoy and Gaimard mention that an odour similar to that around an electric machine is given out by luminous marine annelids.

Amongst the Terebellidæ, as first shown by Grube, none excel the genus *Polycirrus* in the brightness of the phosphorescence and the ease with which it is elicited. Mere blowing on the water of the dissecting-trough suffices to cause in the British *Polycirrus* the most vivid pale bluish luminosity, which gleams for a moment along every one of the remarkably mobile tentacles. Long before Grube, however, had discovered the phosphorescence of *Polycirrus*, our patient and laborious countryman, Sir J. Graham Dalyell,[1] had noticed it in the group, for he mentions that when irritated *Terebella figulus* gives out the most copious blue refulgence, intermingled with a reddish flame. Another member of this family, viz., *Thelepus*, is only faintly phosphorescent in life, but when decomposition has made progress it gleams in the vessel with a pale lambent light, somewhat like phosphorus in air.

In the pelagic Tomopteridæ certain peculiar structures on the parapodia, formerly supposed by some to be eyes, and by others simply glandular organs, were lately found by Professor Greeff[2] to be luminous organs, which, though glandular, have a considerable nervous supply, including a ganglion.

Panceri's observations on the luminous annelids of Naples and the peculiar type *Balanoglossus* (Enteropneusta) have recently added considerably to our knowledge of the subject. He specially describes, in *Chætopterus*, the structure of the phosphorescent glands in the great pinnules and other parts, which produce the luminous mucus. With some reason, he concludes that two kinds of phosphorescence are present in annelids, viz., one which is the result of purely nervous action, and another which is due to this *plus* a luminous secretion.

A Turbellarian, viz., *Planaria retusa*, was mentioned by Viviani[3] as luminous, but this feature appears to be rare in the group; and the same may be observed of phosphorescent Rotifers, one of which (*Synchæta baltica*) was described by Ehrenberg.[4] Giglioli,[5] again, records a *Sagitta* which showed a feeble luminosity in the posterior region of the body.

The minute forms amongst the Crustacea (chiefly Copepoda) were recognised as phosphorescent by Athanasius Kircher in 1640, and have been mentioned by most authors who have alluded to the subject since that date.[6] Thus Viviani gives seven species from the shores of Genoa, and Tilesius no less than nineteen luminous crustaceans from Krusenstern's voyage. Dr. Baird describes the light given out by those met with in his cruises as brilliant in the extreme, and Vaughan Thompson added considerably to our knowledge of *Sapphirina* and of the luminous schizopods, an example of which had been discovered by Sir Joseph Banks, and described by Macartney.[7] Most authors agree that the minute forms, such as the Copepods, give a sparkling appearance to the surface of the water. The light in these, according to Lesson, proceeds from glands placed on the sides of the thorax; while Giglioli found the luminous organ of the cosmopolitan *Sapphirina* in the anterior part of the thorax. On the other hand, Captain Chimmo[8] thought it was decomposing food in the stomach, and Professor Moseley[9] in certain cases entertained a similar opinion. The phosphorescence of the Euphausiidæ was a prominent feature in the voyage of the 'Challenger,' brilliant flashes being emitted on capture from a series of spots along the trunk and tail. Mr. Murray also met with a diffused light in the Faröe channel when dredging in the 'Triton,' and he attributed this to the

[1] *Powers of the Creator*, vol. ii. p. 210.
[2] *Zoologischer Anzeiger*, 1882, p. 384–87.
[3] *Op. cit.* p. 13.
[4] *Op. cit.* p. 128.
[5] *Op. cit.* p. 498.
[6] Professor G. S. Brady has recently observed phosphorescence in some Pontellinæ.
[7] *Phil. Trans.* 1810, as 'Cancer fulgens.'
[8] *Euplectella*, &c. 1878.
[9] *Op. cit.* p. 574. (*Naturalist on the 'Challenger.'*)

phosphorescent organs of *Nyctiphanes norvegica*, M. Sars, one of the same group. Professor G. O. Sars describes these organs as composed of a series of coloured globules, the lens-like body of which acts as a condenser, and thus enables the animal to produce at will a bright flash of light in a given direction.[1]

Marine phosphorescence has some of its most striking examples amongst the Tunicates. One of the best known instances is that of *Pyrosoma*, the light from which has been so graphically described by M. Péron, Professor Huxley, and other naturalists who have had an opportunity of observing it. It proceeds in each member of the compound organism from two small patches of cells at the base of each inhalent tube. These cells contain a substance resembling fat. *Salpa* has frequently been mentioned as a luminous form by many authors, but Delle Chiaje found that in the Mediterranean *Salpa pinnata* was not phosphorescent; and amongst the multitudes of Salpæ which for some weeks abounded at Lochmaddy in North Uist, neither the former nor the *Salpa spinosa* of Otto exhibited this property, though a spark was occasionally seen in the nucleus in some specimens, probably from the food. Giglioli likewise is doubtful concerning them, but in one instance a brilliant rose-coloured light appeared in the nucleus. *Doliolum*,[2] on the other hand, shone with a greenish tint, while examples of *Appendicularia* which he encountered in various seas were chameleon-like in their luminosity, and often gleamed with great brightness.

Various mollusks exhibit the property of phosphorescence. Fabricius ab Aquapendente mentions *Sepia*, Panceri *Eledone*, Adler *Chama* and '*Dactylus*.' The best known is *Pholas dactylus*, which possesses two wavy bands and triangular organs of ciliated epithelium on the inner surface of the mantle. These secrete a luminous substance, soluble in ether and alcohol, which illumines the excurrent water. The light is also maintained for a long time during putrefaction, as in the case of *Thelepus*. Panceri found that carbonic acid extinguished the light, but that air re-illuminated it, just as Johannes Müller had previously observed in a vacuum and in air. The light is monochromatic, the bands having a constant place in connection with the solar spectrum (from line E to line F).

Several Pteropods likewise contribute to the phosphorescence of the sea. Thus Giglioli noticed that a *Cleodora* gave out a vivid reddish light, while a *Criseis* and a *Hyalæa* were luminous at the base of the shell. He mentions also a large unknown Heteropod[3] in the Indian Ocean, which glowed with a reddish phosphorescence. Amongst the Dermatobranchs, *Phyllirrhoë* has the same property. Giglioli further found that *Loligo sagittatus* and a small *Octopus* gleamed all over with a whitish luminosity.

Phosphorescence in living fishes appears to have been accurately observed within a comparatively recent date, though the luminosity of dead fishes has been known from very early times, and has been the subject of many interesting experiments such as those of Robert Boyle on dead whitings,[4] and Dr. Hulme on herrings.[5] I do not mean to say that the literature of the so-called phosphorescent fishes is scanty, for it extends from the days of Aristotle and Pliny to modern times, but that the writers have had little reliable evidence in regard to living fishes to bring forward. Thus of upwards of fifty fishes entered by Ehrenberg in his list it is hard to say that one is really luminous during life. In many cases it is probable that the supposed phosphorescence of large forms, such as sword-fishes and sharks, has arisen from the presence of multitudes of minute phosphorescent animals in the water, just as the herring causes a gleam when it darts from the side of a ship. Professor Moseley, for instance, observed in the 'Challenger' that when large fishes, porpoises, and penguins dashed through phosphorescent water, it was brilliantly lit up, and their track marked by a trail of light. The same feature is observed in hooked fishes, and it is known that fishermen are doubtful of

[1] '*Challenger*' *Narrative*, Zoology, I. part ii. pp. 740–43.

[2] *Vide* also Mr. Murray's observations in Prof. Herdman's 'Report on the Tunicata of the "Triton,"' *Trans. R.S.E.*, vol. xxxii. p. 112.

[3] *Op. cit.* p. 497. [4] *Phil. Trans.* 1667, pp. 591–93. [5] *Ibid.* 1800, p. 161.

success when the sea is very phosphorescent, for the presence of the net in the water excites the luminosity and scares the herring. Little is known with regard to the luminosity of the 'Pearl-sides'[1] of our own shores, though from its wide distribution this lack of information seems to be remediable.

One of the most striking instances of phosphorescence in living fishes is that of the luminous shark (*Squalus fulgens*) found by Dr. Bennett. This is a small dark-coloured shark, which was captured on two or three occasions at the surface of the sea. It emitted without irritation a vivid greenish luminosity as it swam about at night and it shone for some hours after death. The phosphorescence appears to be due to a peculiar secretion of the skin. The eyes of the shark were more prominent than usual in such forms.[2]

In recent times phosphorescence has generally been associated with deep-sea fishes. Thus in a narrative of the early part of the voyage of the 'Challenger'[3] Sir Wyville Thomson mentions ranges of spots or glands producing a phosphorescent secretion on the body of a fish pertaining to the Sternoptychidæ a species of which (*Argyropelecus hemigymnus Cocco*) is included by Mr. Francis Day in his history of British fishes. In a new *Echiostoma* (one of the Stomiatidæ) also the two rows of probably phosphorescent dots along the body were red, surrounded by a circle of pale violet.[4] Dr. Günther[5] observes that many deep-sea fishes have round, shining, mother-of-pearl bodies embedded in the skin. These are supposed to be producers of light, and they have been observed to be phosphorescent in two species of Sternoptychidæ. He further states that the whole muciferous system is dilated in deep-sea fishes, that is, fishes inhabiting 1,000 fathoms or more, and that the entire body seems to be covered with a layer of mucus, the physiological use of which is unknown; it has been noticed to have phosphorescent properties in perfectly fresh specimens.

Having thus briefly reviewed the leading features of phosphorescence in marine animals, a glance may now be taken at the supposed causes and purposes of this provision.

I do not deem it necessary to go into detail with regard to the numerous views which have been advanced to account for the phosphorescence of marine organisms, for these range over a very wide area—from its production by electricity, the constant agitation of the water, by putrefaction, by luminous imbibition, to its manifestation as a vital action in the animals, or a secretion of a phosphorescent substance. Ehrenberg considered it a vital act similar to the development of electricity, and sometimes accompanied by the secretion of a mucilaginous humour which is diffused around; while others, such as Meyen, thought it only a superficial oxidation of the mucous coat, or a luminous secretion from certain glands. Some believed that a liquid containing phosphorus was secreted, and that this underwent slow combustion; while others explained that it was a nervous fluid modified by certain organs to appear as light. Coldstream thought it was due to an imponderable agent, and that phosphorus or an analogous substance might enter into the organs producing it. De Quatrefages, again, affirms that it is produced in two ways: (1) by the secretion of a peculiar substance exuding from the entire body or a special organ; and (2) by a vital action independent of all material secretion. Panceri was strongly impressed with the importance of fatty matter in the forms he examined—such as *Pennatula*, the Medusæ, Beroïdes, Pholades, *Chætopteri* and *Noctilucæ*—the phosphorescence arising from the slow oxidation of this substance; the nervous system of the living animal, however, being capable of producing a momentary oxidation more rapid and more intense, accompanied by light.

It will be observed that in the Protozoa the structure of the minute but often very abundant animals which furnish the luminosity clearly proves that

[1] *Maurolicus pennantii*, Cuv. and Val.

[2] The Danish naturalist Reinwardt describes a phosphorescent fish (*Hemiramphus lucens*) from the Moluccas. *Fide* Giglioli, *op. cit.* p. 503.

[3] *Nature*, August 28, 1873.

[4] '*Challenger*' *Narrative*, Zoology, I. part ii. p. 521.

[5] *Ibid.* I. vol. ii. p. 905.

the presence of a well-defined nervous system is not required for its manifestation, the protoplasm of their bodies alone sufficing for its development. There are no glands for secreting it, and in some apparently no fatty matter for slow combustion. In the Cœlenterates the phenomena appear to be more nearly related to nervous manifestations, though in certain cases the luminous matter possesses inherent properties of its own. While in some annelids, such as *Chætopterus* and *Polyirrus*, there are glands which may be charged with the secretion of a luminous substance, it is otherwise with certain Polynoidæ, in which the emission of light appears to be an inherent property of the nervous system. The irritability in the phosphorescent examples of the latter family, however, varies considerably, some, *e.g.*, *Polynoë scolopendrina*, being sluggish, while others, like *Harmothoë*, are extremely irritable. In the Crustaceans the luminosity seems to have the nature of a secretion, probably under the control of the nervous system. In *Pyrosoma* and *Pholas dactylus* a luminous secretion is also a prominent feature, and in both the latter and the annelids decay excites its appearance, as also is the case, to a limited extent, in fishes.

It is evident, therefore, that the causation of phosphorescence is complex. In the one group of animals it is due to the production of a substance which can be left behind as a luminous trail. The ease, for instance, with which in *Pennatula* and other Cœlenterates the phosphorescence can be repeatedly produced by friction on a surface having a minute trace of the material, clearly points to other causes than nervous agency. On the other hand again, as in certain annelids, it is purely a nervous action, probably resembling that which gives rise to heat. The action, moreover, evidently affects the organic chemical affinities of the tissues engaged.

With the exception of such as Macartney, the older authors, who in some cases took an imaginative view of the question, connected the emission of light with the special economy of the deep sea. The speculations to this effect are fairly summarised in 'Brewster's Edinburgh Encyclopædia,' published in 1830.[1] Thus it is supposed that total darkness exists at the depth of 1,000 feet, and that the phosphorescence of marine animals is a substitute for the light of the sun. Moreover, that by these lights the animals on the one hand are guided for attack, and on the other their power of extinguishing them enables them to escape destruction. Fishes are known to prey chiefly at night, and the writer supposes that the phosphorescence of their prey guides them; for, he says, this luminosity is particularly brilliant in those inferior animals which from their astonishing powers of reproduction, and from a state of feeling little superior to that of vegetables, appear to have been in a great measure created for the food of the more perfect kinds. Dr. Coldstream at a later period (1847) reproduced the same views in his article on animal luminosity.[2]

The same notion was brought forward in the 'Report of the Cruise of the "Porcupine."'[3] and special reference was made to the young of certain starfishes, which are stated to be more luminous than the adults, that being part of the general plan which provides an excess of the young of many species, apparently as a supply of food, their wholesale destruction being necessary for the due restriction of the multiplication of the species, while the parent individuals, on the other hand, are provided with special appliances for escape or defence. Thus phosphorescence, it is further asserted,[4] in very young Ophiacanthæ just rid of their plutei, in a sea swarming with predaceous crustaceans, such as *Dorynchus* and *Munida*, with great bright eyes, must be a fatal gift. Some naturalists still appear to hold a similar, though perhaps modified, view. Much caution, however, is necessary in theorising on this head.

In the first place, phosphorescent animals do not appear to be more abundant in the depths of the sea than between tide-marks or on the surface, the latter perhaps presenting the maximum development of those exhibiting this phenomenon.

[1] Chiefly the views of Dr. Macculloch.
[2] Todd's *Cyclop. of Anat. and Phys.*
[3] *Proc. Roy. Soc.* No. 121, 1870, p. 432.
[4] *Depths of the Sea*, p. 149.

Very many of the young that have been indicated as so brilliantly luminous become surface-forms soon after leaving the egg, and thus at their several stages more or less affect the three regions—of surface, mid-water, and bottom.

A survey of the life-histories of the several phosphorescent groups affords at present no reliable data for the foundation of a theory as to the functions of luminosity, especially in relation to food. No phosphorescent form is more generally devoured by fishes or other animals than that which is not; and, on the other hand, the possessor of luminosity, if otherwise palatable, does not seem to escape capture. An examination of the stomachs of fishes makes this clear, except perhaps in the case of the herring, which, however, is chiefly a surface-fish. Further, it is not evident that such animals are luminous at all times, for it is only under stimulation that many exhibit the phenomenon.

Moreover, the irregularity of its occurrence in animals possessing the same structure and habits in every respect, strengthens the view just expressed. Thus, while *Pholas dactylus* has been known from the days of Pliny to be luminous, the common *Pholas crispata* is not so endowed. Two annelids (*Harmothoë imbricata* and *Polynoë floccosa*), abound between tide-marks and closely resemble each other in habits and appearance; yet one is brightly luminous, while the other shows no trace. Instead of luring animals for prey, or affording facilities for being easily preyed upon, the possessors of phosphorescence in the annelids are often the inhabitants of tubes, or are commensalistic on starfishes. Indeed, every variety of condition accompanies the presence of phosphorescence in the several groups, so that the greatest care is necessary in making deductions, especially if these are to have a wide application.

In the foregoing brief outline of the remarkable phenomenon of phosphorescence as it affects marine animals, it is apparent that, though a considerable increase in our knowledge has taken place during the last quarter of a century, much more yet remains to be done. I, however, confidently look forward for further advances, in this as well as in other departments, to the marine laboratories of the country—I mean such institutions as those now in working order at Granton, St. Andrews and Tarbert, as well as the larger establishment proposed to be erected by the Biological Association at Plymouth. These laboratories, it is true, have been tardily instituted, but it is satisfactory to think that at last the zeal and methods of the workers have, and will have, a better field for their exercise than formerly, and that the zoology of the fisheries will obtain that attention which its importance to the country necessitates.

The following Papers and Reports were read:—

1. *On the Tay Whale* (Megaptera longimana) *and other Whales recently obtained in the district. By* Professor STRUTHERS, *M.D., LL.D.*

1. *Megaptera longimana.* Male, 40 feet long. January 1884. Wounded near Dundee. Brought ashore dead at Stonehaven, near Aberdeen. Presented the usual external characters of this species. Pectoral fin 12 feet long, but finger muscles only about half as well developed as in *B. musculus.* Femur entirely cartilaginous, conical form, right 5½ inches, left 4 inches in length. The skeleton was exhibited to the Section, and its chief characters commented on.

2. *Balænoptera musculus.* Male, 50 feet long. Stranded at Nairn, December 1884; exhibited and dissected at Aberdeen. Presented the usual external characters of *B. musculus.* Finger muscles, the same arrangement as described by the author in *B. musculus,* at the 1871 meeting of the Association. Femur cartilaginous, oval form, about an inch in length. The skeleton was exhibited to the Section.

3. *Balænoptera borealis.* Male, 36 feet long. Killed at Widewall Bay, Orkney, December 1884. Whalebone fringe presented soft character since noticed by Guldberg. Femur absent. Finger-muscles nearly the same as in *B. musculus.* Skeleton exhibited to the Section, and the osteological characters which further distinguish it from *B. musculus* commented on, especially stylo-hyal, nasal, cervical

vertebræ, and orbital plate of frontal bone. Ribs, fourteen pairs, the first pair double-headed.

4. *Beluga.* Killed at Wick, 1884. Skeleton and photograph showing natural form, exhibited to the Section.

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2. *Is the Commissural Theory of the Corpus Callosum correct?* *By* Professor D. J. Hamilton, *M.B.*

The results recorded by the author were obtained by certain special methods of preparation. They went to prove that the corpus callosum is not an interhemispherical commissure, as is generally supposed, but that it is in reality the decussation of a particular system of fibres on their way downwards to join the inner and outer capsules. These fibres are not to be confounded with the motor and other direct fibres derived from the cerebral cortex which decussate at some point lower down.

The facts bearing upon the above were briefly as follows:—(1) The fibres can be seen with the naked eye turning down to join the two capsules, after issuing at each side from the tectorial part of the corpus callosum.

(2) They can be traced with the microscope from the corpus callosum continuously down to the two capsules.

(3) The mass of fibres thus turning downwards forms an arch, varying in shape in different localities, but corresponding in extent to the position of the corpus callosum. This arched system of fibres ('the crossed callosal tract') can be exposed by dissecting off the superjacent cortex and medullary substance. Their curved course can then be distinctly seen with the naked eye.

(4) In young embryos of mammals, and more especially in the human embryo of from three to four months, the callosal system of fibres is much more developed than any other, and hence it appears to be more differentiated than in the adult, where it is obscured by the other systems of fibres around it. The course of the fibres in the embryo is exactly similar to that described in the adult. After leaving the corpus callosum they curve downwards in a ribbon-like band to join the two capsules.

(5) The brain of a woman fifty-three years of age was shown, in which the right first and second frontal convolutions had been destroyed probably in infancy. Corresponding with this the tectorial part of the corpus callosum was extremely small, and the *opposite* inner and outer capsules were almost wanting, while those on the *same* side were comparatively well developed. The basal ganglia on the *opposite* side were also extremely small.

(6) The ultimate destinations of those callosal fibres entering the inner capsule are probably the caudate nucleus, the thalamus opticus, the grey matter of the pons, the cerebellum (?), the ganglionic masses in the medulla oblongata, and possibly the spinal cord. Of those entering the outer capsule the following points of attachment had been made out:—the olfactory tract, the optic tract, the inner capsule (a few fibres), and the temporo-sphenoidal lobe.

(7) The callosal fibres derived from the frontal and occipital regions follow essentially the same course as those arising from the vertex.

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3. *The Evidence of Comparative Anatomy with regard to Localisation of Function in the Cortex of the Brain.* *By* Alex. Hill, *M.A., M.B., M.R.C.S.*

The central nervous system is formed as an involuted tube of epiblast, from the cells composing which the nerve fibres grow out. Throughout the greater part of the system the cells form the inner, the fibres the outer portion of the tube's wall. In its anterior part, where the tube is dilated into the cerebral vesicles, a layer of cells is also disposed outside the white fibre tube. Throughout the central grey tube the cells are arranged in groups, from which spring the nerve fibres for each metamer, the cells in each group being distinguishable into those which are con-

nected with sensory, those which are connected with motor, and those which are connected with visceral fibres. The central grey tube includes the optic thalamus, and the key to its constitution is to be found in its segmentation.

The object of this investigation is to determine the relation borne by the several parts of the peripheral grey tube (the cortex mantle) to the segments of the central grey tube, and indirectly, therefore, to the several body nerves. It may be that the processes of the cells of the central grey tube, the commissural nerves, as they may be called, are woven, as it were, when they reach the cortex into a colourless web, or, on the other hand, they may retain and impart to separate regions of the cortex the tone which they have received from sense organ and motor mechanism. The latter of these suppositions is supported by experimental research, for stimulation of particular regions of the cortex indicates the occupation of those regions by the cerebral centres of particular nerves. On such evidence is based the theory of 'localisation of function.' Eventually, however, this theory must be submitted to a comparative test. Animals differ from one another widely in their sensory and motor endowments. Such differences are clearly indicated by the varying cross-sections of their several nerves, and if particular regions of the cortex are in functional relation with particular nerves, the extent of their development will vary with the size of the nerves. To the superficial regional development of the cortex the fissures are the only possible guides. It is, therefore, of the highest importance to determine their homological value; that they may be safely accepted as boundary-lines is shown by the constancy of their arrangement in animals of any one type, the uniformity of their development and progressive extension, and the fact that the first to appear are the most constant in the animal series and the deepest in the individual. To reduce the matter to statistics, the superficial areas of regions bounded by certain fissures should be compared with the cross-sections of their correlated nerves. As yet no system of mensuration has been devised for the cortex. In the more divergent animals, however, the proportional development of the various regions of the cerebrum is obvious to the eye.

In herbivora, which depend for safety upon sight and upon repeated simple movements of the limbs, the internal part of the occipital lobe, as shown by the deflection of the lateral fissure, is large, the sigmoid gyrus small. In carnivora, which depend for their food upon the sense of smell and the complexity of their muscular system, the temporo-sphenoidal lobe and the sigmoid gyrus are both conspicuous for their development. That these great differences do not depend upon the distance apart of the animals phylogenetically is shown by the fact that in the pig, which seeks its food with its nose, the brain approaches the carnivorous rather than the herbivorous type. Amongst carnivora the otter is conspicuous for the small development of its olfactory apparatus; the temporo-sphenoidal lobe is correspondingly small. In this animal the fifth nerve is very large, which accounts apparently for the large size of the convolution which lies in front of the fissure of Sylvius. Cats are remarkable for the uniform development of their senses. With this uniformity is associated a remarkable symmetry of brain. Hearing, however, is in these animals particularly acute; the cortical localisation of this sense appears to be above the processus acuminis of the fissure of Sylvius. In the main these results are confirmatory of those obtained by Ferrier and other experimental physiologists. The order in which the centres are situate on the cortex indicates that the cerebrum has undergone a rotation backwards into a single turn of a spiral coil.

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4. *Report of the Committee for the Exploration of Kilima-njaro and the adjoining Mountains of Eastern Equatorial Africa.*—See Reports, p. 681.

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5. *Report of the Committee for arranging for the occupation of a Table at the Zoological Station at Naples.*—See Reports, p. 466.

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6. *Report of the Committee for promoting the establishment of Marine Biological Stations on the coast of the United Kingdom.*—See Reports, p. 480.

7. *Report of the Committee for promoting the establishment of a Marine Biological Station at Granton.*—See Reports, p. 474.

8. *Report on recent Polyzoa.*—See Reports, p. 481.

9. *Report on the Record of Zoological Literature.*

10. *Report on the Bibliography of certain Groups of Invertebrata.*

FRIDAY, SEPTEMBER 11.

The following Papers were read:—

1. *Recent Observations on the Habits and Instincts of Ants and Bees. By* Sir JOHN LUBBOCK, *Bart., F.R.S.*

2. *On the Carpal Bones in various Cetaceans. By* Professor STRUTHERS, *M.D., LL.D.*

Dissections exhibited of the carpal bones and cartilages in *Hyperoodon, Beluga, Globicephalus, Narwhal, Balænoptera musculus, B. borealis, B. rostrata, Megaptera longimana*, and *Balæna mysticetus.* The various carpal cartilages, more or less ossified, shown to be mapped out by fibrous and occasionally by partially synovial articulations. The general conclusion of the author is, a diminution in the number of the second carpal row from *Hyperoodon* to *Mysticetus.* In *Mysticetus*, second row reduced to one cartilage or bone, partially ossified in a 35 feet-long male, entirely cartilaginous in a full-grown female. Sections display these facts fully. The pisiform varies in its development. In some it appears as if partially continuous with the cartilaginous epiphysis of the ulna. In *B. borealis* the trapezoid is wanting, in contrast with *B. musculus.*

3. *Account of the Dissection of the Rudimentary Hind-limb of* Balænoptera musculus. *By* Professor STRUTHERS, *M.D., LL.D.*

A careful dissection was made of the anatomical relations of the femur, &c., in the whale from Nairn, and full-sized drawings were made as the dissection proceeded. The femur is imbedded in fibrous tissue, belonging to transverse and longitudinal aponeuroses. Only a small part of a superficial muscle is attached to it. It is loosely held to the pelvic bone by ligaments. No synovial membrane, but an acetabular cartilage is present, concealed by the periosteum. The terminal fibrous band from the femur expands in fascia some inches forwards. The author's conclusion is, that the femur in *B. musculus* is to be regarded as entirely a rudimentary structure. The paper embraced an account of the formation of the pelvic cavity, and of the muscles and fibrous structures connected with the pelvic bones.

4. *Some points in the Anatomy of Sowerby's Whale* (Mesoplodon bidens).[1] *By* Professor W. Turner, *M.B., F.R.S.*

5. *On the use of Graphic Representations of Life-histories in the teaching of Botany.* *By* Professor F. O. Bower.

The object of this paper was to bring before the notice of teachers of botany such diagrammatic representations of life-histories of plants as had previously been published by the author in the Journal of the Linnæan Society, in a paper 'On Apospory in Ferns,' and with this object the author had prepared a series of figures, of which those relating to the ferns were similar in their main points to those published in the paper above referred to: the series was, however, further extended to the higher forms. It was clearly laid down that in the opinion of the author, and according to his constant practice, these figures are only to be used *after* the chief characters of the plants in question, and their processes of development and reproduction, have been described in detail by the teacher: in fact, that they are intended to serve *only* as a simple recapitulation of the main facts, from which comparative conclusions may be the more easily drawn by the teacher, and presented forcibly to the mind of the student. If used in any other way, there is great danger of the graphic method being a stumbling-block and hindrance to true progress. After describing the proposed diagrams in detail, and giving incidentally a description of the newly-discovered and interesting phenomenon of apospory in ferns, the author proposed the following questions for discussion by the teachers present:

1. Are such diagrams as these to be used at all?
2. Is it judicious to load them with further details?
3. How far may their use be extended to the lower forms?

Supplementary Meeting.—PHYSIOLOGY.

1. *On the Direct Action of Anæsthetics on the Frog-heart.* *By* J. McGregor-Robertson, *M.A., M.B.*

This was an investigation into the action of anæsthetics on the excised heart of the frog. The heart was bound to the Kronecker canule, and connected with the frog-heart apparatus of Ludwig. The recording point of the mercury manometer traced the characters of the contractions on the recording surface of the cylinder of a kymographion.

At intervals nourishing fluid (consisting of defibrinated rabbit's blood, one part, and ·6 per cent. salt solution, two parts) was passed through the heart, the arrangement of the apparatus permitting the nourishing fluid containing a percentage of the drug experimented with being supplied to the heart instead. The anæsthetics used were found to vary in their action according to the dose. A small percentage stimulating the heart, and increasing the rapidity of the movement, a greater percentage lessening both the force and frequency, and a third completely paralysing the heart, and stopping all movement, so that even mechanical stimulation failed to arouse the heart. In all cases, however, a few cubic centimetres of normal fluid restored the heart to its former vigour. The recovering heart passed backwards through the various stages of the action of increasing doses of the anæsthetics.

It was shown with ether that a dose sufficient to stimulate at a low temperature caused complete standstill at a higher temperature (35° C.), and that a dose which

[1] Published *in extenso* in the *Journal of Anatomy and Physiology*, October, 1885.

caused standstill at the ordinary temperature failed to do so at a reduced temperature (5° C.). A heart reduced to standstill by a 1° per cent. solution of ether at a temperature of 35° C. recommenced beating on lowering the temperature.[1]

A marked quantitative difference was shown between the different anæsthetics, as shown in the following table, where the percentage of the drug required to stimulate, to reduce, or to entirely stop the contraction of the heart, is shown:—

—	Stimulating	Reducing	Paralysing
Ether	1 per cent.	1·5 per cent.	2 per cent.
Ethidene dichloride	$\frac{1}{20}$th " "	$\frac{1}{10}$th " "	$\frac{1}{5}$th " "
Bromide of ethyl	$\frac{1}{20}$th " "	$\frac{1}{8}$th " "	$\frac{1}{4}$th " "
Chloroform	$\frac{1}{30}$th " "	$\frac{1}{20}$th " "	$\frac{1}{10}$th " "

A qualitative difference was also shown. Ether and ethidene very much resembled one another. The relaxation after each contraction was complete. With chloroform and bromide of ethyl, however, a marked difference was observed. The heart showed a great tendency to contract spasmodically round the canule. So marked was this, that it was difficult to pass the nourishing fluid through the heart, in order to wash out the drugged fluid. This action was never observed with ether and ethidene when the heart had been fairly under their influence. It was noticed in more than one case, however, that the heart became spasmodically contracted round the canule immediately on receiving the first stimulating dose of the drug. This occurred with ether as well as with chloroform. With ether, however, it rapidly passed off, and did not recur after the full influence of the anæsthetic was felt. It did not so readily pass off with chloroform. The author suggested that such an action on the human heart might account for some deaths from chloroform before any quantity of the drug had been given.

The heart recovered speedily from the influence of ether, but slowly from chloroform. Ether was found not to be cumulative; but this could hardly be said so decidedly of chloroform.

The mixture of chloroform, alcohol, and ether (called the A.C.E. mixture) was tried. It seemed to paralyse the heart even more rapidly than chloroform alone, and none of the evil effects of chloroform seemed to be diminished. [Tracings were shown, and a demonstration of the action of ether on the frog-heart was given.]

2. *On the Action of Cold on Microphytes.*[2] *By* John G. McKendrick, *M.D., LL.D., F.R.S.*

3. *On the Action of Ozonised Air upon Micro-Organisms and Albumen in Solution.* *By* J. J. Coleman, *F.C.S.*

The author described a number of experiments conducted by him in conjunction with Professor McKendrick, F.R.S., being supplementary to their joint investigation upon the influence of cold upon microphytes. Air artificially impregnated with ozone by means of a Ruhmkorff coil, so as to contain a much larger percentage of ozone than any natural atmospheric air, was passed continuously through a 1 per cent. solution of white of egg placed in a glass flask, the inlet and outlet tubes of which were carefully plugged with cotton wool previous to commencing and during the experiments.

It was found from various experiments that a stream of air passed through 100 c.c. of the liquid for 30 hours containing an amount of ozone equal in

[1] Details as regards Ether only found in a paper, 'Ueber die Wirkung des Ethers auf das Frosch-Herz.' *Du Bois-Reymond's Archiv für* 1881.

[2] See *Proceedings of the Royal Institution of Great Britain* and *Proceedings of the Philosophical Society of Glasgow*, 1884–85.

weight to the albumen in solution failed in producing the slightest trace of oxidation, and that the ozonised air passed through the liquid quite unaltered.

During the course of the experiments, and for six days following, the development of micro-organisms ceased; but at the end of that time, and notwithstanding the cotton wool plugs, the liquid became slightly turbid from the presence of organisms.

As dilute hydrogen peroxide is without action upon albumen, the conclusion seems inevitable that albumen is practically indestructible by any atmospheric agency without previous splitting up by micro-organisms, and further that whilst micro-organisms cannot develop, and are probably killed in an ozonised atmosphere, their spores are not easily destroyed by its agency.

These results confirm the surmise of the late Dr. Angus Smith, that putrefaction is a necessary preliminary to oxidation in all cases of *natural* river purification.

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4. *A new Theory of the Sense of Taste.* *By* Professor J. Berry Haycraft.

The author showed that 'quality' in this sense depends upon the nature of the atoms found in the sapid molecule. A study of the periodic law demonstrates that similar tastes are produced by combinations which contain elements, such as lithium, sodium, and potassium, which show a periodic recurrence of ordinary physical properties. Among the carbon compounds, those which produce similar tastes are found to contain a common *group* of elements. Thus organic acids contain the group CO, OH; the sweet substances CH_2, OH. There is no relation between quality of taste and gross molecular weight, except that substances either of very small or very great molecular weight are not tasted at all.

SATURDAY, SEPTEMBER 12.

The following Papers were read:—

1. *On a Model of the Whale.* *By* Captain Gray.

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2. *On the Hybridisation of Salmonidæ at Howietoun.* *By* Francis Day, *C.I.E.*

Among the papers on the fishes of the British Isles, which have from time to time appeared in the 'Proceedings of the British Association,' are several respecting the Salmonidæ. Most of these communications have been restricted to investigations into species and their distribution, or questions as to their artificial propagation, but none to hybridisation.

During the last eleven years, Sir J. R. Gibson-Maitland, at Howietoun, near Stirling, has devoted much attention to this subject, and gone to great expense in order to efficiently carry out the many experiments he has instituted, while he has likewise afforded me facilities for personally watching many of them, and furnished me with data as well as with specimens. This subject, which is among the most interesting problems of fish life, I have selected for communication to this meeting; for, although only some conclusions have been arrived at, I cannot resist feeling that such important Scottish experiments ought to be recorded, so far as they have gone, in the 'Proceedings' of this Association, now that it is holding a meeting in the country were they are being carried out.

Willoghby and Ray, as early as 1686, alluded to hybrid fishes, and Pennant (edition 1812) observed 'hybrid fish, for that such exist those persons who have paid most attention to the subject in ichthyology have not a doubt.'

When we consider that the ova of teleostean or bony fishes have, as a rule, to

be fertilised by the milt of the males diffused in the surrounding water, it is not difficult to believe that this fluid from the male of one genus might come into contact with the eggs from fish of another species, genus, or even family, and a hybrid offspring be thus occasioned. But the size of the micropyle of the ovum and that of the spermatozooid of the milt must be of conforming capacities or fertilisation would be a physical impossibility.

Fraisse alludes to a hybrid offspring between a brook-trout and a burbolt, or between fishes belonging to two distinct families; and in the 'Bulletin of the United States Fish Commission' in 1882 is an account of a hybrid between a fish pertaining to the herring family, *Clupeidæ*, and the striped bass, *Roccus lineatus*, a percoid which supplied the milt.

Livingston Stone observed in 1869 that he had crossed the yellow perch, *Perca flavescens*, with the glass-eyed perch, *Lucioperca*, when the embryos continued to develop until the seventh day, and then ceased to do so. Crosses have also been effected between the golden tench, *Tinca vulgaris*, and the common carp, *Cyprinus carpio*; the rudd, *Leuciscus erythrophthalmus*, and the gold carp, *Carrassius auratus*; the roach, *Leuciscus rutilus*, and the bream, *Abramis brama*; between the rudd and the bream; the chub, *Leuciscus cephalus*, and the bleak, *Alburnus lucidus*, &c.

Restricting ourselves to the recorded instances respecting hybridisation among the Salmonidæ in Great Britain, we find it observed upon by Willughby in 1686, when it was remarked that he was persuaded that the salmon and the various forms of trout interbreed; and many authors in this country have erroneously asserted that par were hybrids, until this question was set at rest by the fish culturists. Mr. Shaw, in 1841, observed that his 'experiments with the ova of the common trout and salmon had been quite successful;' that 'those produced between the salmon and the salmon-trout appeared to partake more of the external markings, silvery coating, and elegance of form of the par than any of the others. Those produced between the salmon and the common trout, and between the common trout and the salmon-trout, had in every respect more the appearance of the common trout than the former.'

The Ashworths, in 1853, remarked upon rearing offspring from the ova of trout fecundated by salmon milt. Davy, in 1858, also observed that Mr. Reynolds mixed together the roe of the lake-trout and the fluid milt of the char, and in seventy days young fish were hatched.

The ponds at Howietoun, where the breeding of the Salmonidæ are carried on, are thirty-two in number, constructed in accordance with whether they are intended to accommodate breeders or for rearing purposes; the whole being surrounded by a strong paling five feet high, with an iron spike six inches in length surmounting each post.

The first question which seemed to require being settled was whether, if salmon were crossed by trout, a sterile or a fertile race of hybrids would result? If they were sterile, would they or would they not possess anadromous instincts? It is evident that, could a breed of fish be procured that would not migrate seawards, such would prove most valuable in the upper waters of rivers, as the Thames, which is so polluted in its lower reaches as to be practically impassable to the finny races, and consequently cannot be frequented by anadromous forms.

Leuchart refers to salmon ova, in 1878, having been fertilised by trout milt. No mention is made of the progeny attempting to spring out of the pond in which they were confined, while ova and milt were procured from these hybrids when twenty-two months of age.

At Howietoun some salmon eggs were hatched in March 1881, and on November 29, 1883, or at thirty-two months of age, milt was procured from these fish; but it was not until November 7, 1884, or when forty-four months old, that ripe eggs were furnished by any of these fishes. It would thus appear that the period at which the pure salmon breeds is at least a season later than the trout when kept under the same conditions.

December 24, 1881, about 20,000 Lochleven trout ova were fertilised at Howietoun with salmon milt, and these hatched on March 9, 1882. From time to time some of these hybrids were examined, but none showed signs of breeding until

May 1885, when they commenced springing out of the pond; and on one being opened it proved to be a female with the eggs developing, and had it lived it would evidently have bred this winter when about forty-four months of age, or at a similar period to the female smolt of the pure salmon. But, unfortunately, owing to the severe drought which the country suffered from during the last summer, the stream ceased to give an adequate supply, and all but two of the 144 fish were found dead. Milt and roe were developing in almost all, and although this experiment has not been successfully completed, it so far demonstrates that hybrids between the male salmon and female trout are fertile at the same period as are pure salmon.

In Leuchart's case the trout was the male element, and his fish commenced breeding near the end of their second year, as is the case with trout. At Howietoun, where the salmon was the male element, the hybrids would have commenced breeding at about the same period as in the salmon. It would therefore seem probable that the male elements in both cases had been prepotent, and also that when the male element in the hybrid has been the anadromous salmon, the young at the breeding season attempt to migrate seawards, and they have not lost their anadromous instincts.

Some more hybrids, similar to the foregoing as regards parentage but only one year old, are at Howietoun, and it is hoped will in due course arrive at maturity.

A set of experiments were likewise instituted at Howietoun into the question of whether the age of the male parent has any direct influence on the health of the hybrid progeny. On November 29, 1883, about 4,500 eggs from a Lochleven trout of the season of 1875 were milted from a salmon par thirty-two months old. The eggs hatched well, but the majority of the young were affected with dropsy of the yelk sac, from which nearly all succumbed before the end of the year. That this dropsy was owing to deficiency in vitality is rendered probable by an experiment I tried at Cheltenham in 1884–5, when out of about five hundred young trout only one had dropsy of the yelk sac, and the egg from which it had been hatched had been kept in brackish water in order to ascertain whether that would preclude its hatching.

On November 11, 1884, about 12,000 eggs of Lochleven trout were milted from a salmon smolt a year older than in the last experiment. About 9,500 hatched on January 28, but many died of dropsy of the sac; and on June 19 about 5,000 healthy young ones were turned into a rearing pond. Dropsy in this experiment did not set in quite so rapidly or severely, neither were so many proportionately affected. In this instance, again, there was evidently deficiency of vitality, probably due to the age of one of the parents, and if so that must have been the male, which was forty-three months old.

Several other experiments were made, but with similar results, which would seem to demonstrate that a sickly or feeble offspring results from crossing young salmon, as par or smolts, with mature trout, no matter how vigorous the latter may be. As a corroboration of this opinion the following experiment, also made at Howietoun, may be quoted. November 14, 1884, about 500 eggs, each having a diameter of 0·17 of an inch, were taken from a Lochleven trout not quite two years old. These were fertilised from another of the same race, but older. But only about a dozen hatched on January 28, 1885, and of these seven lived and were turned out into one of the rearing ponds. This is a very instructive experiment, as not merely demonstrating the small size of the eggs given by young mothers, but likewise as pointing out that such as are obtained from young parents either hatch indifferently or even fail to do so, simply due to deficiency of vitality on the mother's side. This experiment must likewise cause one to hesitate before expecting the eggs of two-year-old hybrids to be good hatchers, another season at least being necessary in order to arrive at satisfactory deductions on this head.

Intercrossings have likewise been carried on at Howietoun between trout and char. On November 15, 1882, about 2,000 eggs of the Lochleven trout were fertilised from the milt of the American char (*Salmo fontinalis*). About one in six failed to hatch, while monstrosities were numerous among the progeny. Some were blind with one or both eyes, others had bull-dog malformations of the snout,

while more or less albinoism existed in such as had the sight of both or of only one eye affected. The general colours of these hybrids were yellowish shot with purple, and reticulated with irregular black bands, spots, and markings on the body, but most closely spotted along the upper surface of the head and back. Dorsal fin yellow, with spots and bands; pectorals black-tipped; anal with its first three rays white, the fin behind this being stained with dark grey; caudal dark edged, and having a few indistinct bars at its base. The colours of the male parent or of the American char predominated over those of the female or Lochleven trout. On November 12, 1884, some males were found to be ripe, but the females not quite so. In this instance, as in others, the males were most forward, while the age of these fish was about two years, rendering it evident that both eggs and milt may be expected in a hybrid between a trout and a char in its second year. The foregoing experiment was repeated on November 29, 1883, and about one in seventeen of the eggs failed to hatch.

The last experiment was now reversed. November 15, 1882, 8,000 eggs of an American char were fertilised from a Lochleven trout. About one in three failed to hatch. The young were much deformed, many had their spines crooked, and in some there was atrophy of their posterior portion with a deficiency of fins generally, especially of the caudal. The colours of these hybrids closely resembled those seen in the preceding experiment, or those of the female fish, the American char predominating over those of the male parent, the Lochleven trout. About eight of these fish still survive.

The next set of intercrossing were between the British and American chars. November 15, 1882, about 9,000 ova of an American char were milted from a char from Loch Rannoch. The mortality among the eggs was nearly one in four and three-quarters. There were no considerable number of monstrosities or malformations. The colours were of a beautiful iridescent purple, with thirteen transverse or par-bands along the sides, the whole of the body being sprinkled with light spots. The front edge of the dorsal, ventral, and anal fins were white, as was also the outer pectoral ray. There were a few dark marks along the base of the dorsal fin. In this experiment the colours mostly partook of those of the male parent or Scotch char, which largely predominated over those of the female parent or American char. By November 12, 1884, the majority seemed to be in a breeding condition.

The final series of hybridisation experiments which I propose alluding to in this paper were intercrossings between the foregoing hybrid races; again, however, drawing attention to the fact that, as these fish were all in their second season, such a young age may account for unsatisfactory results, but each additional year will doubtless be productive of increased interesting facts.

November 12, 1884, 146 eggs were obtained from a hybrid between the British and American chars, and milted from another of the same breed; only six hatched, and these died prior to the period for turning the young into the rearing ponds.

December 6, 1884, 600 eggs, each about 0·15 of an inch in diameter, were obtained from a hybrid between the British and American chars, and milted by one of the same race. Only about fifty hatched on February 23, and of these a single one survived to be turned into a rearing pond.

These hybrids were likewise crossed with the original parent stock. November 12, 1884, 1,350 eggs of a Lochleven trout were milted from a hybrid offspring from the Lochleven trout, crossed by the male American char. About twelve of the eggs 'eyed,' but only three of these embryos arrived at a full size, but even they failed in hatching out, dying in their shells.

November 12, 1884, 4,500 eggs taken from two Lochleven trout were milted from a hybrid offspring from the British and American chars. 1,292 eggs were picked out dead from the hatching trays, 1,568 were unimpregnated, only a little more than one-third hatched, and among these were many deformities and a few dropsies. A great mortality occurred among these young fish, and only 320 lived to be turned into the rearing pond.

It would appear from the foregoing that the following conclusions may be more or less drawn:—

1. Salmon and trout, trout and char, and different species of char, may interbreed and give rise to fertile hybrids.

2. Hybrids raised from Lochleven trout eggs fertilised by salmon milt breed in their fourth year, similar to young female salmon kept under the same conditions.

3. The anadromous instinct is not lost in these trout and salmon hybrids.

4. Judging from the period of breeding in the foregoing hybrids, the male element is prepotent.

5. In hybrids raised from Lochleven trout eggs fertilised by the milt of the American char, the male element would appear to be prepotent, if we judge simply by the colour of the offspring.

6. In hybrids raised from American char eggs fertilised by the milt of the Lochleven trout, the female element would appear to be prepotent, if we judge simply by the colour of the offspring.

7. In hybrids raised from American char eggs fertilised by the milt of the British char, the male element would appear to be prepotent, if we judge simply by the colour of the offspring.

8. In all instances of hybridisation between different species, as between salmon and trout, or trout and char, numerous instances of malformation and great mortality occur among the offspring, but much less when two forms of char are intercrossed.

9. In intercrossing hybrids both the eggs and milt were found to be fertile, but the malformations and mortality very great. The parents, however, at Howietoun are not yet of sufficient age to admit any safe deductions on this head.

10. The age of the parent exercises great influence on the vitality of the offspring, for, when very young, we may expect a large percentage of malformations, as well as dropsy and other diseases, in the offspring.

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3. *On the Identification of the British Mosses by their Distinctive Characters.* *By* Mrs. Farquharson, *F.R.M.S.*

Since the appearance of Dr. Braithwaite's 'British Moss Flora,' no advanced student of mosses can complain of the want of an adequate manual in the British language, yet no one who has commenced the study of this order of the *Cryptogamia* can have failed to experience some difficulty in the earlier stages of his work. Without wishing to depreciate the several valuable works on the subject, I have noticed the absence of any work which deals with the distinctive characters of mosses, apart from those of a general nature. I feel sure the want is much felt by young students, who find it difficult to classify mosses especially. The plan which I have found useful is to separate the essential differing characters of each genus in this manner:—

Andreæa.—The capsule splitting into valves, but adhering at its apex.

This character alone isolates this genus from all others. It is also a help to have a plate or drawing near the description of each genus.

The species in like manner. I have found it most desirable and useful to ascertain one (if not more than one) distinctive character, which can be readily carried in the mind's eye, whereby a species can be recognised from its fellow in the same genus.

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4 *On the Flora of Caithness.* *By* James F. Grant.

At present there exists no published flora of Caithness, beyond the plant-list in 'Topographical Botany,' and the various lists printed in the different reports of the Botanical Exchange Club and of the Botanical Record Club. The late Robert Dick, of Thurso, made an exhaustive examination of the flora of Caithness; but he left no MS. notes, and his herbarium contains few Caithness specimens; and such as there are seldom have any locality affixed. Owing to the absence of woods and forests, Caithness is singularly deficient in many of the more common British wild plants; and, as the county is generally low-lying, there is a paucity of alpine

forms, such as do occur frequently growing on the sea cliffs, e.g., *Saussurea alpina* (D.C.). The most characteristic plant of the Caithness cliff-pastures is *Primula Scotica* (Hook.), which occurs very abundantly all along the east and north coast of the county. It flowers three times a year, and is generally found in conjunction with *Scilla verna* (Huds.), and occasionally with *Oxytropis Halleri* (Bunge). Of the flora of the moist, sandy 'links,' or downs, *Juncus Balticus* (Willd.), *Carex incurva* (Lightf.), *Carex pauciflora* (Lightf.), *Blysmus rufus* (Link), and *Viola Curtisii* (Forster), var., are typical representatives. *Carex aquatilis* (Wahl.) var. *Watsonii* is common to nearly all the streams of the county. A *Carex* new to Britain, viz., *Carex salina* (Wahl.) var. *Kattegatensis* (Fries)—the Norwegian 'saltvands star'—was discovered last year near the mouth of the Wick River. It is somewhat like *C. paludosa* (Good.) in appearance, with long, aristate, and dark purple-coloured glumes, and is a native of Iceland, Lapland, and Scandinavia. Critical genera, such as *Salix* and *Hieracium*, are well represented in Caithness, but there are few *Rosæ*. The nature of the surface is not favourable to the growth of aquatic plants. *Nuphar pumilum* (Sm.) and several Potamogetons and Charæ may be got on some of the lochs. There has this year been made out in Caithness a new British grass, *Calamagrostis strigosa* (Hartm.) —the Scandinavian 'stivhaaret ror'—which is somewhat like *C. stricta* (Nutt). It grows in marshy ground near Castletown. *Hierochloa borealis* (R. and S.), discovered by Dick, has almost disappeared from Caithness for the last twenty years, but this year it has been observed on the Thurso River many miles up. The northern and exposed position of Caithness causes slight differences of form and structure in many plants, compared with more southern forms.

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5. *On Chinese Insect White Wax.* *By* A. HOSIE.

The author began with a reference to the European and Chinese writers who mention Chinese insect white wax. He goes on to say that, although the province of Ssu-chuan, in Western China, where he has been stationed for the last three years, is the chief wax-insect and wax-producing country in the empire, insects and wax are found in other provinces. Mr. Hosie was called upon by the Foreign Office to collect for Sir Joseph Hooker specimens connected with, and all possible information on, the subject of this industry, and he states that the present paper is a revision, with additions, of a report already published in a Parliamentary paper in February last. He describes the insect-producing country, the tree on which the insects are propagated, the insects themselves, and their transit from the valley of Chien-chang, their breeding-ground, in the west of Ssu-chuan, across the mountains to Chia-ting Fu, the habitat of the wax tree. This tree is then described, and details are given of the treatment of the insects, their suspension on the trees, the depositing of the wax, and of a parasite on the insects. The method of removing the wax from the branches of the tree and of preparing it for market is then explained. The author then detailed the result of an examination of the insects after the wax has been fully deposited, finally passing to the annual quantity of insect white wax produced, its value and uses.

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6. *On the Existence of Cephalopoda in the Deep Sea.* *By* W. E. HOYLE.

Evidence of the existence of Cephalopoda in the deep sea has hitherto been wanting, but a certain amount seems to be now forthcoming in the case of the genera *Cirroteuthis*, *Bathyteuthis* and *Mastigoteuthis*.

None of these forms (except one species of *Cirroteuthis* from the arctic seas) were known prior to the days of deep sea investigation, nor have any of them been taken by a surface net, nor by any other means than a dredge or trawl which had been down into deep water.

The genus *Bathyteuthis* seems to present structural peculiarities fitting it for an abyssal existence, in certain of which it agrees with *Mastigoteuthis*, although they differ markedly in other respects.

7. *On the Echinoderm Fauna of the Island of Ceylon.* *By* Professor F. JEFFREY BELL, *M.A.*, *Sec.R.M.S.*

The author gives an account of the remarkable advance in our knowledge of the Echinoderm fauna of the island of Ceylon. Till 1882 some four species were known from the island; forty-five are now known, and some six Holothurians remain to be investigated. These advances are due partly to the collection of Professor Haeckel, but chiefly to the industry and activity of Dr. W. C. Ondaatje.

MONDAY, SEPTEMBER 14.

The following Report and Papers were read:—

1. *Report on the Aid given by the Dominion Government and the Government of the United States to the encouragement of Fisheries, and to the investigation of the various forms of Marine Life on the coasts and rivers of North America.*—See Reports, p. 479.

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2. *On the Size of the Brain in Extinct Animals.* *By* Professor O. C. MARSH.

The main points were the following:—

1. All Tertiary mammals had small brains.
2. There was a gradual increase in the size of the brain during this period.
3. This increase was confined mainly to the cerebral hemispheres, or higher portion of the brain.
4. In some groups, the convolutions of the brain have gradually become more complex.
5. In some, the cerebellum and the olfactory lobes have even diminished in size.
6. There is now evidence that the same general law of brain growth holds good for birds and reptiles from the Jurassic period to the present time.

To these may be added the following:—

7. The brain of an animal belonging to a vigorous race fitted for a long survival is larger than the average brain of that period in the same group.
8. The brain of a mammal of a declining race is smaller than the average brain of its contemporaries of the same group.

This question is more fully discussed in the author's monograph on the 'Dinocerata,' just published by the United States Geological Survey.

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3. *On the Systematic Position of the Chamæleon, and its Affinities with the Dinosauria.* *By* Professor D'ARCY W. THOMPSON.

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4. *On the Hind Limb of Ichthyosaurus, and on the Morphology of Vertebrate Appendages.* *By* Professor D'ARCY W. THOMPSON.

A skeleton ascribed to Ichthyosaurus platyodon in the Anatomical Museum of Edinburgh University exhibits certain remarkable peculiarities in the hind-limb, which perhaps render it the most primitive limb known in vertebrates above fishes.

In the first place, the femur has articulated with it three bones, identifiable as tibia, intermedium, and fibula, as in Marsh's *Sauranodon,* and as in the limb

figured as *Pliosaurus portlandicus* by Owen ('Fossil Reptiles'), but ascribed to *Plesiosaurus Manseli* by Hulke (Q. J. G. S. 1883, Suppl. p. 52). This therefore is an additional proof that the primary location of the intermedium is in the 'propodial' segment of the limb.

The limb of Sauranodon contains in its next segment four bones, and so probably, to judge from its articular surfaces, did that of *Pliosaurus*. That is to say, granted that the bones already mentioned are rightly identified, we have in the proximal segment of the tarsus a *tibiale*, a *fibulare*, and *two centralia*. In the Edinburgh *Ichthyosaurus* we have *one centrale* only; and, moreover, we have again in the next succeeding segment *three bones* only, whereas we have five in the corresponding region of Marsh's *Sauranodon*. So far then we have three longitudinal series of bones, and these three rows continue distinct to the distal extremity of the limb. Two other longitudinal series of bones exist: one, a somewhat irregular series of rounded ossicles, is applied to the tibial side of the limb, commencing immediately distal to the tarsus, but not directly articulated with it; the other, commencing at the same level, is inserted between the median and external or fibular row. If we may consider the ground-plan of the limb apart from these last two series, we have here simply three longitudinal series of bones, symmetrically articulated with the extremity of a basal segment. While the limb of Sauranodon seemed to be a weighty argument in support of Gegenbaur's theory of the primitively double nature of the centrale, the present example seems to me a still more potent argument against it; for the common type of Ichthyosaurian limb is undoubtedly intermediate between that of the present example and the typical cheiropterygium of the higher vertebrates; and we pass from our present case to the typical Ichthyosaurus by transverse cleavage of the centrale, and the apportionment of its outer moiety to the interstitial digit.

It is equally easy to pass downwards from this limb to the fin of fishes. Assuming the femur to represent the basipterygium, we have here three basalia, which by elongation and segmentation may be supposed to have given rise to the distal portion of the fin. And the limb has a great though not genetic resemblance to that of Polypterus, where the basalia are reduced to four, or as in one specimen which I have dissected, actually to three. It need hardly be said that this view is wholly incompatible with Gegenbaur's theories; and indeed Wiedersheim has confessed that if the limb of Sauranodon be confirmed, it must lead to the complete recasting of our idea of the vertebrate limb. But it remains to be seen whether the Dipnoan fin is explicable on this hypothesis. In the fin of *Protopterus* the segment articulating with the pelvis, is, I take it, a true basipterygium. To it I find attached two small nodules of cartilage, between which is the main axis of the fin: here we seem to have three basalia, one only of which is elongated or segmented, as are all in our Ichthyosaurus. While in Ceratodus we are reduced to supposing that this one segmented ray has branched laterally, to give breadth and strength to the fin.

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5. *On the Origin of the Fishes of the Sea of Galilee. By* Professor EDWARD HULL, *LL.D., F.R.S.*

When preparing a memoir for the Palestine Exploration Society on the physical history of Arabia Petræa and Palestine I was confronted with two biological problems: one, on the origin of the fauna of the Sea of Galilee (or Lake of Tiberias); the other, on the cause of the extreme dissimilarity between the faunas of the Red Sea and Mediterranean, notwithstanding the ascertained fact that the seas themselves have been physically connected within very recent times. With the former problem I propose here to deal as far as the fishes are concerned; with the latter I shall deal presently.

The abundance of the fishes which inhabit the waters of the Sea of Galilee is known both from sacred and secular history, and has been testified to by several recent observers. The characters and habits of these fishes have also been ably dis-

cussed and illustrated, especially by Canon Tristram[1] and Professor L. Lortet,[2] from which it has been determined that nearly one-half of the species are peculiar to the lake and its tributaries; while of the rest only one—namely, *Blennius lupulus*—belongs to the ordinary Mediterranean fauna; two others—namely, *Chromis Niloticus* and *Clarias macracanthus*—are found in the Nile; seven other species occur in the rivers of South-western Asia; and ten more are found in other parts of Syria. Tristram considers that this assemblage points to a close affinity of the fauna of the Jordanic basin with that of the rivers of Tropical Africa (Æthiopian); but what most strikes the observer is perhaps the number of species special to Jordanic waters, sixteen out of a total of thirty-six species being peculiar. This view seems to be borne out also by an analysis of the molluscous forms, which are for the most part also peculiar, for no less than sixteen species of *Unio* are special to Jordanic waters.[3] Assuming that the forms which are common to Jordanic and other waters have been distributed in a manner similar to that by which we have to account for the distribution of lacustrine forms in other parts of the world, we have yet to account for the presence of the forms which are special and peculiar.

This leads to a consideration of the manner in which the Jordanic basin was first formed and afterwards modified; and without entering here into this wide question, which I have endeavoured to deal with in the memoir above referred to, I may be allowed to summarise my conclusions somewhat as follows:—

In the first place, it must be recollected that as the whole region on both sides of the Jordanic valley was originally overspread by strata of the Eocene period (known as the *Nummulitic Limestone*), this region formed the floor of the ocean down to the close of the Eocene period; the only possible lands in the district may have been those of the crystalline rocks of the Sinaitic group of mountains.

The Geological period which succeeded, that of the Miocene, was that in which land first appeared in the Palestine area. The bed of the sea was locally elevated into dry land, but at the same time most of the leading physical features by which that land is now diversified were traced out and finally determined. Chief amongst these was the line of the great Jordan-Arabah depression—marked out by a line of fault or displacement of the strata, ranging from the slopes of the Lebanon on the north to the Gulf of Akabah on the south. It seems to me probable that as the land on either side of this depression was being elevated, the displacement of the strata on either side of the great fault was also proceeding, and the floor of the sea was subsiding along the line of the Jordan valley. An inland lake of considerable extent was thus formed, whose waters were first derived from those of the ocean itself, in which were enclosed the fishes and mollusks and other forms which inhabited these waters themselves. There are good grounds for believing that once the lake was enclosed and shut off from the outer sea by a barrier of land, it was never again physically connected with the outer sea. The saddle of the Arabah valley, rising some 600 feet above the highest limit to which the waters of the old Jordanic lake ever ascended, would have proved an effectual barrier towards the south.[4] Towards the west the barrier would have been much more elevated. Hence the living forms in the waters of the inland salt lake became isolated from those of the ocean, and had either to adapt themselves to their new conditions or to die out.

We may suppose that the first to disappear would be the corals, crinoids, and starfishes. On the other hand, fishes, mollusks, and crustaceans, having greater powers of adaptation, would in many cases survive. Meanwhile the law of 'descent with modification' would now come into operation, and we may suppose that throughout the Miocene and Pliocene periods the process of modification in form, colour, and habit gradually proceeded. The fittest forms would survive, and

[1] 'Fauna and Flora of Palestine,' preface, p. xii, *Mem. Palestine Survey* (1884).

[2] 'Poissons et Reptiles du Lac de Tibériade,' *Archives du Musée d'Histoire Naturelle de Lyon*, tome iii. (1883).

[3] Tristram, *ibid.* p. 178. The mollusks have been also recently described by M. A. Locard, *Malacologie du Lac de Tibériade* (1883).

[4] See *Mount Seir, Sinai, and Western Palestine*, pp. 95 and 99, &c.

differentiation between those of the outer and inner seas, resulting, as we have seen, in almost an entire specific change, was effected.

The above view seems in accordance with recent observations regarding the adaptability of many marine forms to new lacustrine conditions, provided the process of change is sufficiently gradual. Professor Sollas, whose memoir on 'The Origin of Fresh-water Faunas'[1] is very suggestive, arrives at the conclusion that, as the conversion of comparatively shallow continental seas into fresh-water lakes has taken place on a large scale several times in the history of the earth, this has been accompanied by the transformation of some of the marine into fresh-water forms. The Jordan valley lake, originally salt, has shrunk back into two or three lakes connected by a river. The Dead Sea alone remains salt and lifeless. The waters of the Sea of Galilee are fresh, and teem with life. In reply to my inquiry whether the above views would harmonise with his own, Professor Sollas writes: 'I have always regarded the curious fishes of the Sea of Galilee as evidence of a previous marine communication, but it never occurred to me to speculate as to the age of that connection. If this sea (that of Galilee) were stocked from the Eocene ocean it would fit in very well with the history, as I believe it, of other fresh-water faunas.' It is gratifying to me to have the concurrence on this point of so able an authority. I conclude, therefore, that the special forms of fishes now inhabiting the Sea of Galilee are the descendants of those which lived in the Eocene ocean.

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6. *On the Cause of the Extreme Dissimilarity of the Faunas of the Red Sea and Mediterranean. By* Professor EDWARD HULL, *LL.D., F.R.S.*

The author pointed out that the faunas of these seas have descended from the forms which lived in the Eocene Ocean. In the succeeding Miocene epoch, when the lands rose from the waters, the Mediterranean area was cut off from that of the Red Sea, and as different conditions would be thus brought about, especially in the case of temperature, the faunas would develop independently in both seas. This process of development and differentiation went on throughout the Miocene period and down into the Pliocene, when the lands were again submerged to a depth of 220 to 250 feet, and a connection of the two seas was re-established. But the depth of water over the connecting strait not being greater at its minimum than about 200 feet, although allowing a commingling of the littoral and shallow water forms, would have been insufficient to bring about a general community of species, especially those inhabiting the deeper waters on both sides, and when the land again rose, and the isthmus was established, the forms which had crossed from sea to sea would afterwards die out. From this it has resulted that the faunas of the Mediterranean and Red Seas are almost entirely dissimilar, only 18 species, according to Professor Issel, being common. It would be an interesting inquiry, which of these faunas more resembles the original Eocene stock.

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7. *On the Morphology of the Human Arterial System. By* Professor A. MACALISTER, *F.R.S.*

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8. *On the Viscera of* Gymnotus electricus. *By* Professor CLELAND, *M.D., F.R.S.*

Independent of its electric organs, this fish has a number of remarkable internal peculiarities. The curious spongy protuberances of the mucous membrane of the buccal cavity are well known to zoologists. The two swimming bladders are remarkable for their relation to the kidneys; the anterior swimming bladder being a small structure between their anterior extremities, and the larger posterior swimming bladder being situated altogether behind their united hinder ends, while the duct of the latter ascends by the left side of the renal outlet, to be joined by the

[1] *Scientific Trans. Royal Dublin Society*, vol. iii. (ser. II.).

duct of the other bladder before entering the gullet. The pylorus also is remarkably contracted. But the most striking and altogether curious arrangements are seen on the ventral wall of the abdomen. The intestine passes forward the whole length of the abdominal cavity to the vent, and on its under side is a long renal duct as wide as itself, and opening immediately behind the vent; while, opening into this duct close to its outlet, are the ducts of the two ovaries, which lie one on each side, their morphologically anterior extremities placed posteriorly, as if in process of development these organs had been pulled round from their proper subvertebral position until completely inverted.

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9. *On the Spiracle of Fishes in its relation to the Head, as developed in the Higher Vertebrates.* *By* Professor Cleland, *M.D., F.R.S.*

A very extraordinary mistake can be shown to be prevalent among embryologists, to the effect that the spiracle corresponds with the tympanum and external auditory meatus in the higher vertebrates. This is not the case. The spiracle is pre-oral; the tympanum is post-oral. The apparent sequence of the spiracle with the branchial clefts occurs, as Balfour described it, in the embryo of the dog-fish; but for all that, and although it has rudimentary external gills attached to its margins in the embryo, it is in front of the mandibular arch and above the maxillary lobe. Between the middle and lateral frontal processes is the nostril; between the lateral frontal process and the mandible is the space into the upper part of which the eyeball projects, and from which the lachrymal duct is developed; while between the first and second visceral lobes is the external ear; and it is highly probable that the upper part of the first branchial cleft is homologous with the clefts in front of and behind the lateral frontal process. Thus a certain amount of homology would exist between the spiracle of fishes and the lachrymal duct.

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10. *On the Tail of* Myxine glutinosa. *By* Professor Cleland, *M.D., F.R.S.*

The dorsal and anal fins of *Myxine* are continuous at the tail. They consist of numerous rays, which, when the integument is removed, are seen to be of fibrous structure imbedded in a thin membrane. But the inferior rays of the tail differ from the superior, in that the hindermost of them are supported by a triangular plate of cartilage about half an inch long, lying beneath the chorda dorsalis, and continued into about twenty-four longer or shorter processes. In front of them, at the anterior inferior angle of the triangle, is a small bifurcated process, ending in two slight dilatations, which support the hindermost pair of mucous glands. The triangular plate is of a variety of cellular cartilage allied to the structure of the chorda.

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11. *On the Nucleus in the Frog's Ovum.* *By* George Thin, *M.D.*

The paper describes conditions of the nucleus as observed in ova of *rana temporaria*, between the stages of division into four segments, and that of the end of segmentation when the ovum has assumed a moniliform or mulberry appearance. The appearances described were those observed when sections of ova hardened in bichromate of potash had been stained by picro-carmine. They refer exclusively to changes which carmine-staining shows takes place in certain unformed constituents of the nucleus. In the paper the nuclear network is left out of consideration, the methods of preparation not having brought it satisfactorily under observation.

The conditions observed might be classified as follows: 1st. A *tablet nucleus*,[1] in which the distinctive carmine-staining was found associated with an unformed substance which infiltrates the yolk substance in certain parts of the segments.

[1] A literal translation of *Täfelchen*, the word used by Goethe. It is more appropriate than such terms as 'yolk granules,' &c.

That this is a stage of the nucleus is shown not only by the distinctive staining, but by the well defined nuclear area, the size of the latter and its relations to characteristic accumulations of pigment. In this stage the yolk tablets in the nuclear area are of the same size as those of the surrounding yolk substance of the segments. 2ndly. A *diffuse granular nucleus,* in which in the carmine-stained nuclear area there are imbedded minute yolk tablets smaller than those in the surrounding segment; and also frequently pigment granules. 3rdly. The *homogeneous nucleus* in which the nuclear substance stains homogeneously in carmine. It has distinct boundaries and contains neither yolk tablets nor pigment. 4thly. The *shrunk nucleus* in which a crescent-shaped shrivelled homogeneous substance represents the nucleus. The *shrunk nucleus* may occupy a small part of a hole which equals in area the usual size of a homogeneous nucleus. 5thly. Simple holes are found which from their size and relations to pigment correspond to the position of nuclei. Near these holes one or more *tablet nuclei* or *granular nuclei* are found in the segment.

Although the nuclei are generally found round, yet they are frequently found in various other shapes in the sections, for example, as narrow strips or as club-shaped and crescentic bodies.

The nucleus is sometimes found homogeneous at one part, and in the condition of the tablet or diffused granular nucleus at another, the granular or tablet condition being on the periphery of a round, or at the extremity of a fan-shaped nucleus.

The nucleus may be in direct contact with the substance of the segment, or may be separated from it by a perinuclear area. The perinuclear area may consist of minute breaking down yolk tablets, or may be constituted by a space filled with a homogeneous unformed substance, which does not stain in carmine, and which contains neither yolk tablets nor pigment.

Division of the Nucleus.—An elongated nucleus may be found divided transversely by a narrow line which is either unpigmented or contains pigment. This line may only partially extend through the nucleus. More frequently two nuclear areas are found connected by traces of carmine-stained nuclear substance sprinkled amongst the yolk tablets of the segment. Sometimes two tablets or granular nuclei, removed to a considerable distance from each other, are found linked by this carmine-stained substance. Frequently two such nuclear areas are found in an undivided segment without any such connecting link. Less frequently, two homogeneous nuclei are found close together in a space which is free from yolk substance or pigment; more than two newly formed nuclei may be found in a segment, three and even four being occasionally found. The nuclei may be completely divided and removed from each other before there is any trace of division of the segment.

Pigment.—There is a well-defined relation between accumulations of pigment and division of the nucleus. Pigment is found mixed with minute tablets in the granular nucleus. It may penetrate into the interior of a tablet nucleus in a fine line. In the other stages it is not found within the nucleus, but is found external to it, either in immediate apposition or separated from it by a perinuclear area. Pigment tracks may be traced directly from the periphery of the ovum to nuclei.

Pigment in relation to the Segments.—Pigment is found either equally diffused or collected in masses, or forming distinct rings, or around holes within the segments. Between the segments it may be found either as a single slender dividing line, or as a line which is split at intervals by a space, or it may traverse the segments in various directions in lines.

If, as may be taken for granted, the pigment itself is passive in the assumption of these forms, then its distribution indicates currents within the segment which have a special relation to the nucleus. These currents it is thus shown penetrate from the periphery to the nuclei, and in the tablet and granular stages they penetrate the substance of the nucleus. The accumulation of pigment around and outside the perinuclear area, and its disappearance from the nucleus, indicates a centrifugal current. There are thus in the segments both centripetal and centrifugal currents of which the nucleus is a centre.

The pigment has no causal relation in the nuclear changes, as they are found (more especially in the lower pole), in the absence of pigment.

Thus although the author has been unable to trace the detailed changes of karyokinesis in the division of the nuclei in the frog's ovum, he has observed appearances associated with a substance which stains in carmine, which to some extent harmonise with it. From a nucleus which has arrived at a certain stage a substance escapes into the surrounding part of the segments, and there becomes a centre of an area in which the yolk tablets are dissolved and a new nucleus forms, this nucleus passing through the various stages above described. The newly formed nuclei have the power of dissolving the yolk tablets, of assimilating the substance of the segment, of becoming the centres of currents which must have an influence on its nutrition, and which probably are intimately connected with the subsequent division of the segment that succeeds the development of the new nuclei. Nuclei observed in ova which were divided into four segments, and in those which after eighteen to twenty-four hours had developed into the moniliform or mulberry stage, show that the stages of development are the same in both instances.

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12. *On the Structure and Arrangements of the St. Andrews Marine Laboratory. By* Professor McIntosh, *M.D., LL.D., F.R.S.*

The marine laboratory at St. Andrews was formerly a temporary wooden fever-hospital, 60 feet in length, but as it was only used for a few months some years ago, it was readily obtained for its present purpose. The accommodation consists of a tank-room, two work-rooms, a larger and smaller, an attendant's room, and engine house. Sea-water is obtained from the sea, which comes within a few yards of the laboratory, by means of a gas-engine, vulcanite pump, and pipes. The sea-water is first pumped into a granolithic underground tank, then to a high-level cistern, from which it runs by gravitation through the tanks. The latter are at different levels, and various supplementary vessels are easily added as required by resting them over the tanks and leading the sea-water into them by india-rubber tubes. The situation of the laboratory, which is on a narrow tongue of sand between the harbour and the sea, is most favourable, since the fishing-boats supply many interesting specimens on the one hand, and the beach is rich in marine life, both amongst the rocks and in the sand.

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13. *Remarks on the work at the St. Andrews Marine Laboratory during nine months. By* Professor McIntosh, *M.D., LL.D., F.R.S.*

Amongst mammals several porpoises were examined, one a full-grown female 5 feet 2 inches long, recently delivered and full of milk. The rich yellow milk was examined by my colleague, Professor Purdie, who found in 100 parts by weight—water, 41·11; fat, 45·80; caseine, 11·19; milk sugar, 1·33 (?); mineral salts, 0·57.[1]

The detailed study of the development of many of the food fishes has been carried out by Mr. Prince. These include the cod, haddock, whiting, gurnard, common dab, and common flounder. The ova and development of other fishes were likewise examined, *e.g.*, rockling, lump-sucker, *Cottus scorpius,* Montagu's sucker, 15-spined stickle-back, herring, bib, ling, eel, skulpin, gunnel (Yarrell's blenny), wolf-fish, viviparous blenny, and glutinous hag. The young of many fishes from the rocks were kept under observation, and the food and parasites of others both in their young and adult condition received due attention.

The reproductive organs and development of various annelids, starfishes, ascidians (including *Pelonaia corrugata*), crustaceans, and mollusks (including the common mussel of Mr. J. Wilson), were studied more or less completely. Artificial fecundation had to be resorted to in the case of the common mussel by Mr. Wilson.

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[1] *Chemical News*, Oct. 1885.

14. *On the Chemical Composition of the Milk of the Porpoise.* *By* Professor PURDIE, *Ph.D.*, *B.Sc.*

Professor McIntosh having kindly placed at my disposal a small specimen of milk which he extracted from the mamma of a porpoise, I have made an analysis of it, the results of which are given below:—

	In 100 parts by weight
Water	41·11
Fat	45·80
Albuminoids	11·19
Milk Sugar (?)	1·33
Mineral Salts	0·57

The milk was of a yellow colour and thick consistency; its specific gravity was almost identical with that of water.

The most remarkable point about the chemical composition of the milk as compared with that of other mammals, is the very high percentage of fat which it contains, a constituent which the habit of life of the cetacean no doubt requires in larger proportion. The quantity of material at my disposal being very small, the results of the analysis cannot pretend to great accuracy, and it must be noted that though the analysis represents the milk as containing a small quantity of sugar, the presence of that substance in it is doubtful. Having no more material at my disposal, I was unable to confirm my observation.

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15. *On certain processes formed by Cerapus on Tubularia indivisa.* *By* Professor MCINTOSH, *M.D.*, *LL.D.*, *F.R.S.*[1]

The members of the domicolous subdivision of the amphipodous crustaceans are characterised by the very general habit of forming tubes of various kinds, which constitute dwellings as well as nests for the young. Others, again, excavate tunnels in tough clay or mud, like *Corophium*. The subject of the present remarks, which is apparently closely allied to *Cerapus difformis*, and very prettily barred with red on the antennæ, constructs groups of flexible tubes, which vary in diameter according to the size of the occupant, on stems of *Tubularia indivisa*, very much as Stimpson describes in his *Cerapus rubricornis* on the shores of Grand Manan. Instead of being formed, however, as Stimpson says, of 'fine mud and some animal cement,' those of the British species have, in addition, grains of sand, bristles, and spines of annelids, hairs of sea-mice, and many fine horny fibres apparently derived from the byssi of horse-mussels.

On the same stems of *Tubularia* are certain remarkable processes which project from the cœnœcium like branches. These filamentous structures are of a dull greyish hue (that of the mud), and are very slightly tapered distally. The basal region, however, is distinctly larger, especially where fixed to the zoophyte. Their length varies from three to four inches, and all seem to be incomplete. They are smoothly rounded, and resemble the fine muddy tubes secreted by certain annelids; but they are quite solid, and composed of the same constituents as the tubes abovementioned, though perhaps the foreign bodies such as bristles and spines are more conspicuous. These, moreover, are neatly arranged with their long axes parallel to that of the process, and especially abound towards the base of the filament, which thus is more rigid and tougher than the distal region, into the composition of which mud, sand, and the secretion chiefly enter. In consequence of this structure, the distal region slightly curves downward in the ordinary position in the water, while the proximal stands stiffly outward. These processes are generally fixed to the main stem of the *Tubularia*, though occasionally they spring from the

[1] This and the three following published with figures in the *Ann. Nat. Hist.* for December, 1885.

tip of a young example attached to the former, or stretch from the extremity of a parasitic sertularian.

These filamentous processes are usually at some distance from the nests or tubes of the crustaceans which climb actively on them. Whether they give them a larger area for the capture of prey in comparative security, or afford a more extensive surface for the temporary arrest of minute larval or other forms on which they feed, is unknown. It is probable, however, that processes so elaborate subserve some useful purpose to the species, and are not the result of mere purposeless formation.

16. *On a new British Staurocephalus.* *By* Professor McIntosh, *M.D., F.R.S.*

This form was first noticed in a small aquarium belonging to Mr. Sibert Saunders, at Whitstable, in 1884, and he kindly forwarded living specimens to the St. Andrews Marine Laboratory for examination. It is about 8 or 9 mm. in length by 1 mm. in breadth, including the bristles. The number of segments varies on each side of 30, exclusive of those without bristles. It is characterised by a horseshoe-shaped head furnished with a pair of short dorsal tentacles of two segments, and a similar pair on the ventral surface. Four eyes occur dorsally, one on each side behind the dorsal tentacle, and a smaller pair just in front of the nuchal fold. Each foot has dorsally a short cirrus, and ventrally a somewhat larger one, besides a long process of the setigerous region. Dorsally are long simple bristles, inferiorly bristles with an articulated terminal piece. The jaws consist superiorly of a pair of curved maxillæ and about six small dental plates on each side. The anterior edge of these in ordinary views from above is minutely denticulated. The mandibles present a crown and anterior projection. This form comes nearest the *Staurocephalus minimus* of Langerhans [1] from Madeira.

17. *On certain remarkable Structures resembling Ova from Deep Water.* *By* Professor McIntosh, *M.D., LL.D., F.R.S.*

When carrying out the work for Her Majesty's Trawling Commission, an old willow-basket came up in the net on August 15, 1884, fifteen miles S.E. of the island of May. This, besides other interesting marine forms, had attached to it certain peculiar dull, yellowish structures resembling ova, about an eighth of an inch in diameter. They adhered to each other in the form of a single layer along the bark of one of the willows. They were nearly circular, with a short, slightly curved distal appendage. The capsule was yielding, but tolerably tough, and the contents consisted of a soft and cohesive gelatinous substance of a pale colour. The minute structure was explained. No change occurred, though kept for a considerable time in the marine laboratory, until decomposition set in. Their relationships are at present unknown.

18. *On the Ova of Callionymus lyra, L. (the Skulpin).* *By* Professor McIntosh, *M.D., LL.D., F.R.S.*

So little was known about the breeding of this fish that the most recent work on British fishes, viz., that of Dr. Day, gives nothing worthy of note. At St. Andrews it was found that the ovaries were not sufficiently advanced for reliable observation in regard to the condition of the eggs till the middle of June, but that from this date till about the middle of August several favourable examples occurred. The ovaries in a well-developed female form a somewhat cordate mass, bifid in front but connate posteriorly, and, like the spermaries, covered with a silvery coating of the peritoneal lining. The ova are very minute (·028 to ·03 of an inch in diameter) and translucent, and are truly pelagic. In appearance they are characteristic. Each has a very fine hyaline *zona radiata*, furnished externally

[1] *Zeitsch. f. wiss. Zool.*, Bd. XL. p. 257.

with a series of hexagonal reticulations like those of the ruminant honeycomb stomach. When the edge of the ovum is examined, the septa bounding the reticulations stand out prominently, and in sections made by Mr. Prince these would appear to be modifications of the outer surface of the *zona radiata*. In some views the free edges of these reticulations are minutely crenate. The yolk, as in many other pelagic ova, is transparent.

So far as observed, a considerable number of ova—proportionately to the size of the ovaries—seem to arrive at maturity simultaneously.

This ground-loving fish has therefore truly pelagic eggs; but, unfortunately, this season the sexes were not simultaneously procured in a condition to carry out the development.

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19. *On the Zoocytium or Gelatinous Matrix of* Ophrydium versatile. *By* Professor ALLEN HARKER, *F.L.S.*

Unusual opportunities of obtaining the colonies of *Ophrydium versatile* in very large quantities during the past summer have led to my devoting some time to the study of the gelatinous matrix, in or upon which the infusorium is found. I have got as much as a quart measure full of the colonies in a few minutes in our canal. The apparently spheroidal mass is not solid, but forms an irregular hollow spheroid, and in or upon the outer surface the individual *Ophrydia* are situated at regular distances from each other. The colony is at first found attached to the submerged stems of *Myriophyllum* and *Anacharis*, at as much as two or three feet below the surface, the hollow usually containing a large bubble of gas. After a while the colony detaches itself and rises to the surface, and floats about for some days. The infusoria then leave the zoocytium, which continues to float about, attracting a miscellaneous collection of diatoms and other algæ, infusoria, worms, and arthropodous larvæ, becoming a perfect menagerie of living beings.

In perfectly fresh slices of the colony, under a power of 300 diameters and upwards, a large number of unbranched threads, regularly divided by septa, are invariably to be found, and on one occasion I found one of these threads in active motion, suggesting a filamentous alga allied to *oscillatoria*. The dried gelatinous substance has by many botanists been described as a plant, and Suhr described it as *Coccochloris pila*; but Rabenhorst excludes it, and adds, 'Specimina omnia quæ vidi in algis meis Europæis sic et duo in herbario Suhriano pertinent ad Ophrydium versatile' (*animalculum!*).

Wrzesniowski, in his paper on *Ophrydium* in the 'Zeitschrift für Wissenschaftl. Zoologie,' 1877, figures and describes the long dichotomously branching thread-like pedicle of the animals, and this is recognisable in suitably mounted slices under $\frac{1}{4}$ obj., but, so far as has been observed, the threads I describe do not appear to be similar. It is just possible they may be accidental visitors in the colony, though they very closely resemble specimens of *Aphanothece stagnalis* which I have examined, this being an Alga with a dense gelatinous exudation.

The gelatinous mass associated with *Ophrydium* is of a very obstinate character, and resists the action of almost any reagents but strong sulphuric acid.

After boiling in distilled water for half an hour the gelatinous character is almost unaltered, and only after prolonged boiling in weak potassium hydroxide could the solution of the jelly be obtained. After some hours' boiling, and subsequent treatment with weak acetic acid to get rid of the carbonate of lime (whole minute crystals are distributed throughout the mass), the residue, a flocculent mass, is found to consist entirely of the threads before mentioned. These do not change colour on the addition of strong nitric acid; nor, again, do they give satisfactorily the celluloid reaction with iodine and sulphuric acid. Their nature remains an open question. The author adds some further notes on the animal. When light is allowed to fall only on a part of the colony, all the animals in a very short time congregate to that part of the zoocytium, and on the whole being freely exposed again to light they partially spread themselves over the surface, though a majority leave the matrix altogether. In tanks they showed no disposition to form new colonies as described by Savile Kent, but collected in masses

at the bottom. A sufficient quantity was thus obtained to extract the colouring matter by alcohol in suitable quantities for examination, the result being the separation out of chlorophyll with smaller quantities of xanthophyll, as the author has done in the case of Euglena.

Supplementary Meeting.—PHYSIOLOGY.

1. *On the Action of Atropine on the Secretion of the Kidney; its Evidence as to the Mechanism of the Secretion.* By J. McGregor-Robertson, *M.A., M.B.*

The author stated that he employed atropine because of an idea that its action might aid in distinguishing between different parts of the process of secretion in the kidney.

Assuming the filtration theory regarding the nature of the process in the glomerular tufts, and having regard to the elaborate researches of Wilibald Schmidt of Voigtland on filtration, the author did not see any good reason for asserting that albumen did not filter through the glomerular walls into the tubules. If albumen was filtered through, what became of it, was the question. It was a reasonable view that it might be reabsorbed by the renal epithelium. In connection with this view, the author was struck with the statement that atropine had no such effect on the urinary secretion as it had on the salivary secretion. It was known that atropine abolished the salivary secretion by paralysing the salivary cells, and that it abolished the secretion of sweat, probably by a similar action. If atropine acted at all on the secretion of the kidney, it might be supposed to act in a similar way by paralysing the renal cells. If the view that these cells reabsorbed the albumen were correct, paralysis would cause the appearance of albumen in the urine. It was these considerations that led the author to undertake the experiments. The experiments had not as yet answered the question regarding albumen. The results obtained, following the injection of atropine, were:—

1. A fall in the production of water, and
2. A rise in the production of urea.

At a later stage, when the animal was recovering from the effects of the drug, there were:—

1. A rise in the production of water:
2. A fall in the production of urea, and there was also a suspicion of albumen, but on this last the author did not wish, at the present stage of the inquiry, to lay stress.

The experiments seemed to show clearly that the process by which water was separated was different from the process by which urea was separated, since invariably the quantity of the former fell when that of the latter rose.

The author did not wish to commit himself to any theoretical explanation, but he pointed out that, accepting Heidenhain's view regarding the separation of urea by the renal cells, the atropine might stimulate the cells, thus causing increased separation of urea and increased absorption of water, and that some degree of exhaustion following the stimulation would account for the fall in the separation of urea and the rise in the quantity of water, less of it being reabsorbed by the partially exhausted cells.

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2. *On a Chemical Difference between Living and Dead Protoplasm.* By Oscar Loew, *Ph.D.*

It has been long since a question why the manifold chemical changes going on in a living cell of a plant or an animal suddenly cease with the death of the cell. None of the hypotheses offered proved to be satisfactory. The living cell is

undoubtedly full of a wonderful chemical energy, and the most complicated syntheses are performed with ease. Think of a bacterium, that lives and multiplies in acetate of ammonia solution, and forms its albumen, fat, and cellulose from this compound of so simple a composition! Think of the continued production of protoplasm that goes hand in hand with the perpetual destruction by respiration, and certainly a most energetic chemical activity becomes evident.

In 1875 the first attempt was made to trace this energy back to a peculiar chemical constitution of the albumen that composes the protoplasm. The physiologist E. Pflüger, in Bonn, was the author of this hypothesis. He believed the albumen to contain cyanogen groups, which take up the elements of water, and thus the albumen would lose the agility of the atoms and change into another substance of less chemical energy—the dead albumen.

This hypothesis hardly found the recognition it deserved. It was only Detmer, Professor of Botany in Jena, who in 1880 accepted and defended similar views. In his opinion the chemical change of the albumen takes place by atomic displacement, and while in the living albumen a most energetic motion of the atoms leads to a continual dissociation, this ceases entirely in the dead or ordinary albumen. Neither Detmer nor Pflüger made any experiments whatever.

It was in 1881 when, starting from my own hypothesis of the formation of albumen in plants, I was led to the conclusion that the albumen of the living protoplasm contains aldehyd groups which are lost in the albumen of the dead protoplasm by atomic displacement. I therefore concluded that these easily changeable and energetic aldehyd groups could be demonstrated by the action upon an alkaline silver solution. Living cells should give a reduction of the silver solution, dead cells should not. The first experiment succeeded. It was made with an alga named Spirogyra. The slides were exhibited, which under the microscope demonstrate this difference very clearly, the protoplasm is perfectly black in one case, and not at all in the other case, where dead cells (killed by a temperature of 50°, or by an acid) had been submitted to the silver reagent. This silver reagent shows still action in a dilution of 1 part of silver to 200,000 parts of water. Not all objects show this reaction. Objects in which the killing process is performed too quickly cannot give the reaction, the silver solution itself being poisonous. There can also exist many obstacles that prevent the reaction, as presence of chloride of sodium, existence of an impenetrable membrane, &c. The phenomenon known as argyria is probably also founded upon the reaction of the active albumen of living protoplasm. In this case the metallic silver is deposited in different organs of the human body, when treated internally by nitrate of silver.

The kidneys of frogs and caterpillars show also the reaction, young hairs of plants, parts of leaves, roots, and the cells in living wood. Diatoms and infusoria die altogether too quickly to give the reaction; also some algæ of the higher classes behave likewise, and parts of most of the animals.

Many experiments were made to prove that this reaction is caused solely by the character of the *albumen* of the living protoplasm. It will suffice here to mention that I have *shown by analysis* that the oxygen of the reduced silver oxide has really entered into the molecule of the albumen.

The supposition that the reducing atomic groups in the active albumen are nothing but aldehyd groups receives a strong support by the fact that *hydroxylamine* proves to be a poison of the most general character. We know that this substance acts upon all aldehyds with great readiness, even in a very diluted and perfectly neutral solution. Its poisonous qualities can find no other explanation than that it acts upon the aldehyd groups in the living protoplasm, causing disturbances that lead to disorganisation in the cells.

While these experiments prove that the albumen of the living cell is quite a different substance from that of a dead cell, and thus a foundation for an explanation of the great chemical activity of the living cell is furnished, still I am at the same time far from believing that hereby all vital action can be explained. The cause for the divisions of cells, the nervous activity, the growth after prescribed rules, the wonderful differentiation of the various functions of a living body,

the mechanical actions, the construction itself of the protoplasm, that appears as a wonderful machinery built up with molecules of active albumen—all this appears as mysterious as heretofore.

[For details see 'Die Chemische Kraftquelle im Lebenden Protoplasma.' I. A. Finsterlin: Munich, 1882.]

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3. *A Comparative View of the Albuminous Substances contained in the Blood of Vertebrate and Invertebrate Animals.* By W. D. Halliburton, *M.D., B.Sc., M.R.C.P.*

Introduction. General remarks on proteids; the division of blood into corpuscles and blood plasma. Lymph and hæmolymph.

A. The proteids contained in the corpuscles. Hæmoglobin.

B. The proteids contained in the plasma. This comprised the greater part of the paper.

1. The globulins; fibrinogen, paraglobulin, hæmoglobin, hæmocyanin.
2. The albumens. The varieties of serum albumen.

The differences between these two classes of proteids, and the methods of separating them employed from the time of Denis to the present day.

The part each plays in the formation of fibrin. The differences noted in these bodies in various classes of vertebrate and invertebrate animals. In considering the vertebrata, special stress will be laid on the differences observed in the serum albumen of warm and cold blooded animals.

Among invertebrata the class of Crustacea will be most fully considered. Hæmocyanin, its composition, properties, distribution, and function. The clot in invertebrata—is it a mere coalescence of cells or plasmodium, or is it due to the formation of fibrin as in vertebrates? Experiments in support of the latter view were quoted.

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4. *On the Striated Muscles in the Gills of Fishes.* By Dr. J. A. McWilliam.

There is present in the gills of fishes a comparatively large amount of muscular substance, and this substance assumes a somewhat unexpected form—that of transversely-striated muscle instead of the non-striated tissue which one might be more ready to expect in such a situation. Striated muscle exists in the gills of all the fishes I have examined—both in Elasmobranchs and in Teleostean fishes, though the relations of the muscular structures are not identical in these two orders. There are two situations in which muscle exists in the gill.

In both Elasmobranchs and Teleosteans a band of muscle entering the branchial arch at its dorsal attachment passes along the arch more or less parallel to its long axis and lying towards its pharyngeal aspect. As this muscular band approaches the ventral extremity of the arch, it thins off and ends. Muscular tissue exists in another situation in the gills—between the two rows of filaments borne by each branchial arch. The inner borders of these filaments are united to one another in Teleosteans by a considerable amount of connective tissue, and in this tissue lies an extensive series of muscular bundles. The muscular fibres arise from the cartilage of the branchial arch or from the surrounding connective tissue, and pass outwards between the branchial filaments to end in a slender tendon which is inserted into the point of junction of the sheaths of the two adjacent filaments.

In the skate the muscular bundles arising from the branchial cartilage are not inserted as in the Teleosteans, *e.g.*, salmon and eel, but pass outwards in the partitions which separate the branchial compartments, and finally become continuous with the muscular tissue lying beneath the integument which lines the exterior of the branchial chamber.

The gill-muscles are innervated by the vagus. Stimulation of the vagus nerve causes contraction of the muscles referred to; this leads to a movement of each gill as a whole, and also an erecting movement of the gill filaments in Teleosteans at least.

A reflex contraction of these muscles can readily be induced by stimulation of various parts, *e.g.*, the spinal cord.

5. *On the Structure of the Intestine in the Hedgehog and the Mole. By* Dr. J. A. McWilliam.

The intestine of the hedgehog, like that of certain other mammals, shows externally no division into a small and large intestine.

I have found that there exists, however, a histological division into parts corresponding to the small and large intestine of man.

In the upper and longer portion of the hedgehog's intestine—that corresponding to the human small intestine—the details of structure are for the most part similar to that of man, with the exception, as one might expect, of valvulæ conniventes. The villi are large and densely set. In vertical sections they show with remarkable clearness the lacteal vessels which they contain. These vessels form a rich plexus instead of a simple loop or a blind tube as in man; they approach the surface of the villus and lie in close relation with the basement membrane, instead of being confined to the median part of the villus and enclosed by a considerable amount of adenoid tissue as in the human villus.

The lower portion of the hedgehog's intestine—that corresponding to the large intestine of man—resembles in the chief points of its structure the human colon. The longitudinal muscular tissue, however, is uniformly arranged around the bowel instead of being collected into three bands.

The transition from the villous part of the hedgehog's intestine to the non-villous part is abrupt, just as is the transition from the characteristic structure of the small intestine to that of the large intestine in man.

The intestine of the mole presents some remarkable features. One of the most striking of these is the entire absence of villi. The mucous surface of the bowel along the greater part of its length is beset with ridges, which are elevations of the mucous membrane projecting into the interior of the intestine. At the lower part of the bowel there are no ridges; this part corresponds to the large intestine of man. The ridged part, on the other hand, corresponds to the small intestine of man. The transition from the ridged to the non-ridged part is comparatively sudden.

The arrangement of the ridges is strikingly different in the upper and lower portions of the ridged part of the mole's intestine. In the upper part the ridges are so arranged as to form a pretty close network with polygonal meshes of various sizes on the internal surface of the bowel. In the lower portion of the ridged part of the intestine the ridges are, on the other hand, arranged longitudinally; they run in the long axis of the bowel, pursuing a remarkable wavy course and maintaining a well-marked parallelism to each other. The transition from this arrangement to that in the upper part of the intestine is very gradual.

The portion of bowel which shows the network of ridges alluded to probably corresponds to a duodenum and jejunum, while the longitudinally ridged part is probably equivalent to an ileum.

Vertical sections show that the structure of the ridges is essentially similar to that of the hedgehog's villi. The lacteals are similarly arranged, and are seen with remarkable plainness without the application of any process of silver nitrate staining or of injecting the lacteal vessels.

The peculiar ridges of the mole's intestine may possibly have some relation to the ridges which are described by Meckel as occurring in the human intestine at a very early stage of development.

6. *On Plant-Digestion, especially as occurring in* Carica papaya. *By* Sidney Martin, *M.D., B.Sc., M.R.C.P.*

1. History of the discovery of proteolytic ferments in the vegetable kingdom—in the 'insectivorous' plants, and in the seeds.

The two different uses of the ferments—(*a*) for the assimilation of nitrogenous

material, and (*b*) for the metabolism of the reserve-proteid. This second use will be chiefly considered.

2. The uncertain state of knowledge of the character of vegetable proteids, with a *résumé* of the latest researches.

Proteids in the juice of the fruit of *Carica papaya*. Action of the proteolytic ferment, papaïn, on animal albumen and on the proteids occurring in the juices.

Discussion of the metabolic changes, especially as regards formation and fate of peptones and crystalline nitrogenous products. Indications for future researches.[1]

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7. *On a new kind of Colour Apparatus for Physiological Experiment.* *By* JOHN AIKEN.

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8. *On the Structure of Hyaline Cartilage.* *By* GEORGE THIN, *M.D.*

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9. *The Preservation and Prolongation of Life to* 100 *years.* *By* PROTHEROE SMITH, *M.D.*[2]

The accuracy and precision which mark the rapid motion of the steam-engine, continuing its ceaseless work apparently without deterioration, afford a type of what has been often observed in regard to the life of man. If the parts, or organs, on the normal condition of which the existence and continuance of our being mainly depends, in the same way, are kept in their place, and free from the friction of counteracting circumstances, the living human machine will also be found to possess macrobiotic powers far beyond what is commonly supposed. The popular objection to this statement consisting of the idea that the limit of natural life is four score years and ten, is proved to be a misconception of the authority on which this assumption relies. Senile decrepitude, leading to premature decay, is shown usually to result from derangement of those mechanical forces which in health sustain the body and its essential vital organs. But when restored, the 'mens sana in corpore sano' will not only be often reinstated, but life also greatly extended so as to warrant the answer in the affirmative to the question, 'Can we attain to the age of a hundred years, and live happily so long and even longer?' In naming certain organs and their functions as essential to healthy life, it will be seen how often they become deranged and interrupted in their action by the altered form of the bony structure of the body, resulting from advanced age or disease. This alteration in the bony structure is a gradual loss of the normal curvature of the spine, causing the back to become ultimately *convex* instead of *concave*, as in its natural sigmoid form, thus throwing forward the head and shoulders into a stooping attitude, and displacing the pelvis towards a *horizontal* plane instead of its natural *inclined* position. This alteration causes a compression and displacement of the various important organs of the body, which impede their action, and result in the gradually progressive deterioration of both the bodily and mental powers in senile decrepitude. The stooping position of the body causes a continued strain upon the muscles of the back in order to support the unnatural overhanging weight in front, consequent on the loss of the natural balance of the body. The disturbing cause of this change is directly attacked, and gradually removed by a simple mechanical appliance, which restores the spine to its natural form and the upright position of the body, and brings the pelvis back to its natural inclined position. For this purpose the 'Pelvic Band' has now been used successfully by the author for many years, effecting this object by a gentle spring action, exerting a continuous pressure *forwards* upon the spine in the hollow of the back, and *backwards* upon the pelvis and shoulders in front. The result thus effected has been in several

[1] For details of results, see *Journal of Physiology*, vol. v.
[2] Published *in extenso* by John Avery & Co., Gallowgate, Aberdeen.

hundred cases a complete restoration of the natural upright position and sigmoid form of the body, accompanied by the recovery of good health with the enjoyment of prolonged life.

Supplementary Meeting.—BOTANY.

1. *On the Application of the Anatomical Method to the Determination of the Materials of the Linnean and other Herbaria. By* Professor L. Radlkofer.

As I have set forth in a speech on the anatomical method, delivered before the Munich Academy in 1883, a real furtherance of systematic botany may be looked for from the employment of anatomical and histological characters.

It is to this application that I have given the designation *Anatomical Method*, and I have exerted myself for years to bring it to bear on systematic botany.

For my own part, I have sought to rely upon anatomical characters in my labours on the Sapindaceæ, and I may venture to say successfully, especially as far as the genus Serjania is concerned, by making use of the anomalous structure of the wood of these tropical climbers in defining the species. On this subject I had an opportunity of addressing this Association at Norwich in 1868; therefore I will not enlarge upon it now.

After having thus initiated the anatomical method and found my expectations therefrom fulfilled, I endeavoured to apply it to other families, such as the Acanthaceæ, the Sapotaceæ, the Capparideæ, &c., as more fully detailed in the beforementioned speech.

Other botanists, I am gratified to see, have followed me in this direction, particularly some of my pupils at the University of Munich, some of whom, like Dr. Hobein, I have induced to investigate isolated families in relation to their anatomical peculiarities; others, Dr. Bokorny and Dr. Blenk for example, to trace certain anatomical characters found in several families all through these families, in order to determine the constancy and systematic value of such characters for each of these families.

By means of the results thus obtained, and to be obtained, I think it is now possible, without very great difficulties, to clear up the doubts respecting the fragmentary materials of the important older Herbaria.

In the first place comes the Linnean Herbarium and the Herbarium of the Hortus Cliffortianus, formed by Linneus, and then the Herbaria of Linneus's predecessors, Plukenet, Sloane, Paul Hermann, &c., upon whose plants Linneus founded the majority of his species.

Thanks to the care of English botanists and English learned societies, these Herbaria, so important for the correct interpretation of Linnean species, have been faithfully preserved intact for a hundred years and more, up to the present day.

And now at the present day is possible what formerly was impossible, namely an exhaustive review of the contents of these Herbaria with references to the writings of their former possessors—now, with the aid of the anatomical method, this might be attempted, and should in my opinion be attempted without further delay. These Herbaria should henceforth not merely be preserved; they should, by the diffusion of a new light on their contents, become useful to everyone in a scientific sense, even to those who are unable to look through them.

As far as the Linnean Herbarium is concerned, Sir Edward Smith in his day endeavoured to extract therefrom a correct conception of the Linnean species; but the slender scientific means of his time enabled him to arrive at the goal in only a few instances. Nevertheless, his contributions to Rees's 'Cyclopædia' on this subject are of great value, and deserve republication in a collective form, in order to make them generally available, as I suggested in the speech alluded to at the beginning.

The work begun by him should now with the help of the anatomical method be resumed and completed.

Perhaps I may be permitted to call to mind an instance in which the sole way of arriving at any certainty regarding the materials in old Herbaria mentioned was by employing the anatomical method. I mean with regard to what is to be understood by *Paullinia curassavica* L. and *Paullinia polyphylla* L., which we now refer to *Serjania*. The same was the case with other species of these diversified and difficult genera, the members of which, in the absence of fruit, often cannot be referred to the right genus, even by one well acquainted with them, except calling in the aid of the anatomical method. And what holds good for these genera holds good for numerous others.

To mention only one more plant, *Sideroxylon mite* L., which I have only been able to thoroughly elucidate within the last few days on having recourse to the Linnean Herbarium; perhaps I may be permitted to explain how the anatomical method alone led to its elucidation.

Sprengel, perceiving that certain of the characters attributed to this plant by Linneus did not accord well with the genus Sideroxylon, regarded it as a species of Myrsine and named it *Myrsine mitis*. Under this name, too, it was found by Dr. Bokorny in the Munich Herbarium, and by him recognised as an exception in respect of a prominent anatomical character denoting the Myrsineæ, being destitute of the internal resin-glands which give the dotted appearance to the leaves. A second similar exception was offered by *Myrsine marginata* Hook.[1] Later investigations on the systematic value of the structure of the wood in various families, carried out by another pupil of mine, Mr. Solereder, led to the supposition that the two plants in question did not belong to the Myrsineæ at all.

With regard to *Myrsine marginata*, fragments of the original plant of which I was able to examine through the kindness of Professor Oliver, an anatomical investigation soon brought to light that it had been wrongly placed, really belonging to the Sapotaceæ rather than the Myrsineæ, and henceforth to be designated *Chrysophyllum marginatum*.

And as to the *Myrsine mitis* Spreng., that turned out to be a species of Ilex, the South African *Ilex capensis* Sond. Unfortunately this result gave no clue to the identity of *Sideroxylon mite* L., and this appeared permanently hopeless; for, on making inquiries, I was informed that it did not exist in the Linnean Herbarium. But after my arrival in England, as I was able to look for it myself, it was easy for the eye sharpened by the anatomical method to detect it, in spite of the absence of flowers and fruits, and to decide that it was nothing else than *Ilex capensis* Sond., which now, according to De Candolle's rules of nomenclature, must be called *Ilex mitis*.

It would seem superfluous to cite other examples in order to demonstrate the value of anatomical characters in systematic botany, and how much science would benefit from a sifting of the older herbaria by the aid of the anatomical method.

Permit me, therefore, to conclude with an appeal to all English botanists to direct their attention and their influence to the accomplishment of the work which I have suggested; in doing which the British Association might perhaps contribute substantial assistance. The thanks of botanists of all times would certainly accrue to England therefrom.

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2. *On the Influence of Impregnation on a Plant.* *By* E. J. Lowe, *F.R.S.*

Some experiments were made in 1884 and continued in 1885 in order to ascertain to what extent a plant was influenced by the impregnation of a flower (*i.e.*, as to whether the effect of impregnation was confined to the solitary individual flower or extended along the branch which produced the flower).

A self yellow mimulus, M. LUTEUS *Willd.* was selected for the experiment, and this was crossed with pollen from a copiously spotted mimulus known as

[1] See Bokorny in *Flora* 1882, pp. 374–376.

M. CASHMERIANUS *of Gardens.* The latter being dwarf in habit, bearing somewhat large, and exceedingly brilliant flowers. Both parents are quite hardy and herbaceous.

Two specimens of *M. luteus* were placed in a greenhouse where there were no other mimuli. When the flower buds were almost ready to burst open, a portion of the flower was cut away in order to get at the pistil, and in this manner three blooms were impregnated with pollen from the *M. Cashmerianus,* and the small flower buds above them were not allowed to bloom.

The second plant was treated in the same manner, but was crossed with pollen from another plant of *M. luteus.*

When the seed pods were nearly matured, three more buds on the same stem (and obviously above those formerly crossed) were allowed to mature, and when nearly ready to expand were cut open and impregnated *in both plants* by pollen from another plant of *M. luteus.* These experiments were therefore :—

1. A self yellow mimulus crossed with a spotted mimulus.
2. A self yellow mimulus crossed with a yellow mimulus.
3. The yellow mimulus (experiment one) again crossed with a yellow mimulus.
4. The yellow mimulus (experiment two) again crossed with a yellow mimulus.

More than a hundred seedlings resulted and bloomed, and *every one of them* were spotted.

There was no difference in the seedlings in experiments two and four, every plant being a copy of *M. luteus,* the two parents.

In experiments one and three, every seedling was spotted and having characters intermediate between the two parents (a yellow flower and a spotted flower). Six, however, had the spots on a white ground, whilst in the remainder the ground colour varied in different shades of yellow. There was not a single plant with a self yellow flower, and there was no difference in the appearance of the flowers in experiments one and three.

These experiments have been repeated with the same results, and the plants are now in flower.

Thus the impregnation of the first flowers was communicated through the flowering branch to the buds forming higher up the stem, and produced seedlings identical with those from the former impregnation, and the second impregnation with a yellow flower was unable to alter the offspring.

It may be mentioned that these experiments disclosed the fact that the two lips of the pistil of the mimulus are exceedingly sensitive, closing rapidly when touched by the brush, either *with* or *without* pollen. Every species of mimulus that has been examined showed this sensitiveness.

From the above cross has resulted a most beautiful strain of hardy mimuli.

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3. *On the Impregnation of Composite Flowers.* *By* E. J. LOWE, *F.R.S.*

A large number of experiments have been made during the last three years on the impregnation of the single dahlias, the result of which may be briefly stated.

If a bloom of the single dahlia be examined it will be found that the marginal portion of the flower-head is in a condition to be impregnated before the centre of the same flower-head, so that in order to impregnate every portion of the flower-head, it is requisite to continue the operation for several days.

Taking advantage of this circumstance, an individual *flower-head* was impregnated three several times with different pollen, so that three distinct breeds of flowers were obtained from one flower-head.

In one example the outer rim was impregnated with clematis-like flowers, the next rim with flowers having a coloured centre, whilst the centre was crossed with flowers having a star-like character, the petals revolved and giving a wheel-like appearance.

In saving the seeds from a ripe seed pod, those along the outer edge were kept

separate from those within this edge, and from those in the centre of the pod. (The shape of the seeds alters from the margin to the centre, but the plants resulting from those on the margin and the centre, if impregnated alike, do not vary).

Thus in composite flowers every individual flower can be made to produce distinct variations on the same flower-head.

An experiment was tried as to whether it required more than one pollen grain to impregnate a flower. A white-flowered dahlia was selected as the seed-bearer, and this was crossed with pollen from a deep red flower. When simply crossed this produced plants having blooms from pink to red, and three plants with white flowers, whilst if crossed with pollen containing four times as many grains from a white flower as from a red one, the result was in 172 seedlings, 79 were pure white, and all the others pale in colour, none being nearly as dark as the red flower from which the pollen had been taken.

The plan adopted to obtain certain proportions of pollen grains was after consideration as follow:—

Four brushes were filled with pollen from a white dahlia, and one brush from a red dahlia, and this was collected from these five brushes on to a larger brush, and this larger brush was the one used to impregnate the example selected.

It is easy to get an approximate idea of the colours to be obtained by certain crosses by the mixture of moist paints or dry powders, and in the case above mentioned, the mixture of four times as much white as red was singularly borne out, as no seedling produced flowers darker than this mixture. Those who are practically aware of the difficulty of raising white seedlings even from the seeds of a white dahlia will understand the success of these experiments, and will be convinced that a number of pollen grains are necessary in order to effect impregnation, or at all events have the power of acting together.

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4. *On the Occurrence of Fungi in the Roots of Orchids.* By J. MACMILLAN.

It has long been known that the mycelia of fungi occur in the roots of orchids. Prillieux[1] saw them in *Neottia Nidus avis,* Reinke[2]. notices their occurrence in Corallorhiza and Epipogon, and several other writers have noticed them. De Bary, in a lecture on symbiosis given at Innsbruck in 1879, also mentions the fact.

As yet no systematic study of the phenomenon has been made. The difficulties attending such study are great. I propose here to record the results of my examination of several species of orchids, chiefly epiphytal orchids.

Epiphytes.

Cattleya Gaskelliana. Plant in full flower, few aerial roots, no trace of mycelia in aerial roots one year old, no trace in fresh shoots of this year.

C. Mendelii. Plant not in flower, in one aerial root mycelia found.

C. Mossiæ. Plant examined three months after flowering, many aerial roots containing mycelia. One root coming from a pseudobulb pushing out a flower contained abundant mycelia.

Oncidium Forbesi. Plant in full flower; no trace in any part of any aerial root.

O. Forbesi. Another plant not in flower; no trace in any aerial root.

O. crispum. Plant not in flower, no trace of mycelia.

O. Krameri. Plant not in flower, no trace of mycelia.

O. fuscatum. Plant not in flower, no trace of mycelia.

Stanhopea grandiflora. Plant in full flower, perfume of flower very powerful, aerial roots abundant and mycelia in these abundant.

S. oculata. Plant examined one year after flowering, many withered aerial roots in which no trace, many new aerial roots with mycelia abundant.

Odontoglossum triumphans. Plant not in flower, numerous pseudobulbs and aerial roots springing from them. No trace of mycelia.

[1] *Annales des Sciences Naturelles,* 1856.

[2] *Flora,* p. 145, 1873.

O. Alexandræ. Plant in flower, no aerial roots on plant.

O. hystrix. Plant with many pseudobulbs, few aerial roots, has not flowered for more than two years, no trace of mycelia.

O. Rossii majus. Plant with many pseudobulbs, few aerial roots; examined five months after end of flowering period, which extended over ten weeks. No trace of mycelia.

O. vexillarium. Leafy plant with pseudobulbs, few aerial roots; examined three weeks before flowering. No trace of mycelia.

O. cariniferum. Plant similar to last, will flower in spring. No trace of mycelia.

Dendrobium nobile. Plant in flower, many old and a few new aerial roots. No trace of mycelia.

D. Cambridgeanum (Cantabrigense?). Many old and few new aerial roots, no trace of mycelia. Plant not in flower.

D. Farmerii. Plant not in flower, several vigorous aerial roots. No trace of mycelia.

D. tortile roseum. Plant like preceding, similar results.

D. Falconerii. Plant examined three months after flowering, many aerial roots old and new, no trace of mycelia.

D. crassinode Barberiana. Plant not in flower, few roots. No trace.

D. primulinum giganteum. Plant strong and vigorous, few aerial roots; no trace of mycelia.

D. bigibbum. Plant has not flowered for two years, has been kept dry, a few new aerial roots springing from apparently withered stems. No trace.

D. formosum giganteum. Plant with few aerial roots. No trace.

D. aggregatum majus. No trace of mycelia one month after period of flowering.

Aerides odoratum. Strong, healthy plant with many large aerial roots. No trace of mycelia.

A. virens. No trace one month after flowering.

A. Lobbii. Examined two months before period of flowering, many thick vigorous roots. No trace.

Saccolabium ampullaceum. Plant with long, thick healthy aerial roots, examined three months after flowering. No trace of mycelia.

S. Blumei. Similar in growth to last. No trace.

S. guttatum. No trace three months before period of flowering.

Cypripedium Laurentium. Plant with thick aerial roots, examined one month after flowering. No trace.

Ada aurantiaca. Examined four months after flowering. No trace of mycelia.

Angræcum caudatum. Plant with long, thick, fleshy aerial roots, examined just before flowering; no trace.

Cypripedium Veitchi. Plant in flower; no trace.

C. Drewi. Plant in flower; no trace.

Helcia sanguinolenta. Plant not in flower. No trace of mycelia.

Dendrobium filiforme. Plant in full flower, few aerial roots. No trace of mycelia.

Cattleya Laurenceiana. Plant strong and vigorous, mycelia abundant in aerial roots.

C. trienne. Like last, very strong development of mycelia.

Terrestrial Orchid.

Disa grandiflora. Plant large, healthy, in full flower. No trace in any underground roots. No aerial roots.

The evidence afforded by these epiphytic orchids as to the nature and function of the fungi growing in them is of a somewhat conflicting character. Before discussing that evidence it will be necessary to glance at the structure of an aerial root.

At the growing apex of each aerial root is a glaucous bright green portion

varying in length in the different species. Above this, receding from the growing apex the epidermis is of a white colour.

A horizontal section shows the aerial root to consist of three concentric rings of tissue.

The *outer* or *velamen* consists of a varying number of layers of cells. In Oncidium about ten, in Aerides two or three. These cells are polygonal, closely packed together, contain no chlorophyll, many are filled with air. These give the velamen its white colour and render it hygroscopic. Through these layers of the velamen many spiral vessels are found.

The middle ring is bounded by two layers of compact cells, the outer endoderm and the inner endoderm. The outer endoderm consists of a row of thick-walled compact cells. In this row at intervals are thin-walled cells leading from the velamen to the central ring. The cells between the outer and the inner endoderm are large with chlorophyll granules, and contain the usual cell contents. The number of layers of these cells varies. I have found most in Aerides, fewest in Dendrobium. The central ring very clearly marked off from the middle ring is composed of a dense mass of fibro-vascular tissue. Next the inner endoderm the xylem and the phloem portions alternate. The thick-walled cells of the inner endoderm lie opposite the phloem portion, and the thin-walled cells opposite the xylem portion. These gradually merge into the large cells of the medulla. They do not play any important part in the investigation.

In which of these rings are the mycelia found? In all the species I have examined they occur invariably in the middle ring. Only in the cells with chlorophyll have I found mycelia; where the mycelia are most abundant the protoplasm of the cells is least. These cells are comparatively empty. Of the various rows of cells in the middle ring or zone the central contain most mycelia. I have never seen a single thread attempt to pass by means of the thin-walled cells of the inner endoderm to the central zone. Nor have I ever seen these threads in the act of penetrating the thin-walled cells of the outer endoderm. In some species of Cattleya, *e.g. Cattleya Laurenceiana*, where the development of mycelia was very strong—the central zone being nearly filled by them—I have never found them penetrating these thin-walled stoma-like cells.

The mycelia are never found in the green terminal growing apex of the root, but are first found just where the velamen with its hygroscopic cells begins. I have traced them from this point all through the aerial root as far as the pseudobulb. This they have never entered in any plant I have examined, nor have I found any trace of mycelia in any other part of the plant—flower, gynandrium, or leaf.

Again, in cells which have little or no protoplasm, the mycelia are strongest and most abundant, while in those cells with most protoplasm, which often gathers in lumps, the mycelia are thinner and less vigorous.

Constitution of Mycelia.

In some cases the hyphæ, for such I consider that part of the fungus which branches and anastomoses, are found towards the posterior portion of the root, while the mycelium portion with few branching threads is found nearer the anterior portion of the root. In *Cattleya trienne* the branches are large, thick, and with node-like swellings like the buckle-shaped swellings on the hyphæ of Basidiomycetes. Sections of the root containing these swellings were sown in a suitable medium. From these swellings came only their mycelium-like threads. In no instance have I been so fortunate as to find any fructification, either in the root or arising from sections sown in a suitable nourishing medium. From the varied appearance of the threads, however, it may be concluded that the fungi belong to different families.

Relation of the Mycelia to Cell-wall and Cell-contents.

The appearance of the cells into which the mycelia have penetrated is not essentially changed by the presence of the fungus. Near the growing apex of the root where the mycelia are first found the cells remain unaltered, nucleus and

protoplasmic bodies are unchanged. On advancing nearer the pseudobulb the cell is often filled with the threads; nucleus, protoplasmic bodies, starch granules seem to have disappeared, and only the fungus with a small quantity of cell sap appears to be left. Such a section, however, when treated with suitable reagents, shows the nucleus among the anastomosing filaments of the fungus without loss of shape or of size.

Often the cell-sap gathers into a lump in the centre of each cell, from the edges of which cell threads run in and surround the lump.

By the application of a sugar solution the plasma is drawn off from the lump of mucilage which once more, after the removal of the solution, swells up as before. From this it is evident that the protoplasmic bodies are not destroyed by the fungus.

The thickness of the cell-wall, too, plays no unimportant part in the distribution of the mycelia. Where the walls are thick the threads have greater difficulty in penetrating, and are not so numerous and strong as in roots where the cell walls are thinner and therefore more easily penetrated.

Schultze's solution colours the cell membrane a beautiful violet colour and makes the threads disappear.

The growing thread appears with its apex at the middle of the cell wall, and where it has penetrated there is a slight swelling, both where it enters and where it emerges from the cell wall. The edge of the aperture where the threads have penetrated is quite smooth, so that it may be concluded that the membrane has been dissolved at the point of penetration.

Entrance of Mycelia into Roots.

In what way do the fungi first enter the aerial roots? I have examined plants recently imported in a shrivelled condition and have found no trace of fungi. Two years after importation still no trace; only when the plants have become established and comparatively vigorous in growth do the fungi seem to enter. That they penetrate the outer covering is evident from the following experiment. A plant of *Platanthera bifolia* was taken whose next year's tubers were ripe and already contained mycelia. These tubers were placed under a bell jar along with tubers not yet containing any trace of fungi. In four or five days these latter were infected. In their outer cells a slightly branched mycelium was found.

Again, does the orchid thrive better with or without the fungus? The evidence for and against is conflicting. I always noticed that the strongest, healthiest plants, those which produced the largest spikes of flowers, contained the most highly developed fungi.

It may be that we have here an instance of symbiosis; it may be that the fungus is imprisoned by the orchid, and made to gather nourishment for it, or afford nourishment to it, or the fungus may be a parasite pure and simple.

It is a noteworthy fact that orchids brought to this country in a dry withered condition begin to grow most vigorously when the aerial roots are entered by the fungi. On the other hand, these roots are not entered until they have attained a certain vigour. Their vigour, therefore, may be the cause of the infection, not the effect of it.

Lastly, the cultivation of these fungi has never yet resulted in the production of any fructification, so that no clue has as yet been obtained as to the genera or species of the fungus.

I hope by the examination of a much greater variety of species of foreign orchids and of our native orchis yet to throw some little light on this subject.

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5. *Notes on Experiments as to the Formation of Starch in Plants under the influence of the Electric Light.* *By* H. MARSHALL WARD.

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6. *On the Flora of Banffshire. By the* Rev. W. S. Bruce.

Banffshire contains over 600 species of flowering plants, besides a considerable number not considered to be truly indigenous. Of these the majority are plants of the British type, which are more or less diffused throughout the country. Very few are English, while, on the other hand, plants of the Scottish type are exceedingly abundant, such as *Pyrola media* and *minor, Trientalis europæa, Goodyera repens,* &c. Of the Atlantic type, *Scilla verna,* found at Banff and Macduff, is the sole representative, while plants of the Highland type are scattered abundantly throughout the length of the county. Many of these are found only in the higher glens and on the mountains at the south-west end of Banffshire, e.g., *Alchemilla alpina, Rubus Chamæmorus, Vaccinium uliginosum* and *V. Vitis-idæa, Saxifraga rivularis* and *S. stellaris, Luzula spicata* and *L. arcuata, Carex rigida, Epilobium alpinum,* &c. The Alpine *Alchemilla* is found along the banks of Fiddich lower down, and the *Sedum Rhodiola* and *Polygonum viviparum* grow on the sea-coast.

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7. *On the Flora of Elgin. By* James Mackenzie.

To the west the ground is irregular, hilly, much wooded, and drained by a rivulet. The plants found are:—

Convolvulus arvensis.
Myrrhis odorata.
Datura Stramonium.
Polygonum Hydropiper.
Hypericum pulchrum.
Ulex nanus.
Pinguicula vulgaris.
Narthecium ossifragum.
Lychnis Flos-cuculi.
Radiola Millegrana.
Bromus sterilis.
Galium Mollugo.
Parietaria officinalis.
Anchusa sempervirens.
Berberis vulgaris.
Polygonum Bistorta.
Papaver somniferum.
Habenaria bifolia.
Gymnadenia conopsea.
Drosera rotundifolia.
Hydrocotyle vulgaris.
Linnæa borealis.
Mentha aquatica.
Helosciadium inundatum.

The coast from the laigh of Moray to Lossiemouth is exposed to the north and is rocky, the cliffs being of various formations.

The plants are:—

Ammophila arundinacea.
Asperugo procumbens.
Carduus tenuiflorus.
Helianthemum vulgare.
Poa maritima.
Ligusticum scoticum.
Scilla verna.
Saxifraga granulata.
Cakile maritima.
Astragalus hypoglottis.
Astragalus glycyphyllus.
Salsola Kali.
Parnassia palustris.
Ononis arvensis.
Elymus arenarius.
Sisymbrium Sophia.
Lepidium campestre.
Reseda luteola.
Glaux maritima.
Conium maculatum.

To the north-east of Elgin, in the low lying part, there is a large tract of marshy ground. Evidently the Loch of Spynie had at one time covered a much larger area than it does at present. Nearer the town the soil is sandy. The plants are:—

Iris Pseud-acorus.
Scirpus lacustris.
Blysmus rufus.
Briza media.
Potamogeton pusillus.
Anagallis tenella.
Triglochin maritimum.
Typha latifolia.

Sium angustifolium.
Hyoscyamus niger.
Melilotus officinalis.
Goodyera repens.
Neottia spiralis.
Polygala vulgaris.
Poterium Sanguisorba.
Teesdalia nudicaulis.
Medicago sativa.
Trifolium procumbens.
Rosa spinosissima.
Hippuris vulgaris.
Veronica Anagallis.
Menyanthes trifoliata.
Ranunculus Lingua.
R. Flammula.
R. aquatilis.
Alisma Plantago.
Alisma ranunculoides.
Potamogeton natans.
Valeriana officinalis.
Cardamine amara.
Nepeta Glechoma.
Knautia arvensis.
Saponaria officinalis.
Ballota nigra.
Verbascum Thapsus.
Anthriscus sylvestris.
Malva rotundifolia.
Carduus acanthoides.
Arum maculatum.
Allium ursinum.
Ranunculus Ficaria.
R. bulbosus.
Asperula odorata.
Plantago Coronopus.
Pyrola media.
Vaccinium Vitis-idæa.
V. Oxycoccos.
Melampyrum sylvaticum.
Trientalis europæa.
Alchemilla vulgaris.
A. arvensis.
A. alpina.

8. *On the Division and Conjugation of Spirogyra.* *By* Dr. J. M. Macfarlane, *F.R.S.E.*

9. *On a Microscopic Fungus in Fossil Wood, from Bowling.* *By* Dr. J. M. Macfarlane, *F.R.S.E.*

10. *On a new Method of preparing the Epidermal Tissues of Pitcher Plants.* *By* Dr. J. M. Macfarlane, *F.R.S.E.*

The author stated that the difficulty he had experienced in getting clean and large pieces of the epidermis from the different surfaces of pitchers induced him to try various methods of preparation. Maceration in caustic potash solution of 2 p.c. strength gave admirable results. The pitchers to be macerated were placed whole in beakers containing the solution and boiled over a Bunsen flame for from ten minutes to two hours. The pitchers of Nepenthes, if young and fresh, had both outer and inner epidermis loosened from the green cellular and fibro-vascular systems after about fifteen or twenty minutes boiling; old or dried pitchers required thirty to sixty minutes. By floating them afterwards in clean water both epidermal layers could be detached with great ease. Pitchers of Cephalotus were macerated after ten to twenty minutes treatment, but those of Sarracenia Heliamphora and Darlingtonia, except when young and tender, required boiling for about two hours, with subsequent maceration for two or three weeks in water. In this way not only could long pieces be obtained for continuous microscopic examination of the surfaces, but bottled hand specimens of the entire inner epidermis of Nepenthes could be made, showing clearly to the naked eye the *attractive, conducting,* and *secreting* surfaces, with associated glands. Bottled specimens and a series of microscopic preparations were exhibited and described, illustrating the paper. It was also pointed out that similar treatment of leaves for preparations of hairs, water and air stomata, &c., gave equally good results in many cases.

11. *On Aberdeenshire Plants as Food for Animals.* *By* William Wilson, Junr.

TUESDAY, SEPTEMBER 15.

The following Report and Papers were read:—

1. *Report on the Migration of Birds.*—See Reports, p. 685.

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2. *Note on the Intelligence of the Dog. By* Sir JOHN LUBBOCK, *Bart., F.R.S.*

The man and the dog have lived together in more or less intimate association for many thousands of years, and yet it must be confessed that they know comparatively little of one another. That the dog is a loyal, true, and affectionate friend must be gratefully admitted; but when we come to consider the psychical nature of the animal, the limits of our knowledge are almost immediately reached. I have elsewhere suggested that this arises very much from the fact that hitherto we have tried to teach animals, rather than to learn from them: to convey our ideas to them, rather than to devise any language or code of signals by means of which they might communicate theirs to us. The former may be more important from a utilitarian point of view—though even this is questionable—but psychologically it is far less interesting. Under these circumstances, it occurred to me that some such system as that followed with deaf mutes, and especially by Dr. Howe with Laura Bridgman, might prove instructive, if adapted to the case of dogs.

I have tried this in a small way with a black poodle named Van, by taking two pieces of cardboard, about ten inches by three, and printing on one of them in large letters the word 'food,' leaving the other blank. I then placed two cards over two saucers, and in the one under the 'food' card I put a little bread and milk, which Van, after having his attention called to the card, was allowed to eat. This was repeated until, in about ten days, he began to distinguish between the two cards. I then put them on the floor, and made him bring them to me, which he did readily enough. When he brought the plain card I simply threw it back, while when he brought the 'food' card I gave him a piece of bread, and in about a month he had pretty well learned to realise the difference. I then had some other cards printed with the words 'out,' 'tea,' 'bone,' 'water,' and a certain number also with words to which I did not intend him to attach any significance, such as 'naught,' 'plain,' 'ball,' &c. He soon learnt that bringing a card was a request, and to distinguish between the plain and printed cards; it took him longer to realise the difference between words, but he gradually got to recognise several. If he were asked whether he would like to go out, he would joyfully pick up the 'out' card, choosing it from several others, and would bring it to me, or run with it in evident triumph to the door. The cards were not always put in the same places, but were varied indiscriminately, and in a great variety of positions. Nor could the dog recognise them by scent, for they were all alike, and continually handled by us. Still I did not trust to that alone, but had a number printed for each word. When, for instance, he brought a card with 'food' on it, we did not put down the identical card, but another bearing the same word; when he had brought that, a third, then a fourth, and so on. For a single meal, therefore, eighteen or twenty cards would be used, so that he evidently was not guided by scent.

No one who has seen him look down a row of cards and pick up the one he wanted, could, I think, doubt that in bringing a card he feels he is making a request, and that he can not only distinguish one card from another, but also associate the word and the object. This is, of course, only a beginning, but it is, I venture to think, suggestive, and might be carried further, though the limited wants and aspirations of the animal constitute a great difficulty.

My wife has a collie which was often in the room when Van brought the food card and was rewarded with a piece of bread, but although the collie begged in the usual manner, it never once occurred to that dog to bring a card, of which, indeed, not the slightest notice was taken.

I then prepared six cards about ten inches by three, and coloured in pairs, two yellow, two blue, and two orange. I put three of them on the floor, and holding up one of the others, endeavoured to teach Van to bring me the duplicate: that is to say, if the blue was held up, he should fetch the corresponding colour from the floor, if yellow he should fetch the yellow, and so on. When he brought the wrong card he was made to return for another till he brought the right one, when he was rewarded. The lessons generally lasted half an hour, during which he brought the right card on an average about twenty-five times. I certainly thought that he would soon have grasped what was expected of him, but although we continued the lessons for about ten weeks, at the end of the time I cannot say that Van appeared to have the least idea what was expected of him. It seemed a matter of pure accident which card he brought.

As it was just possible that Van might be colour-blind, we then repeated the experiment, substituting for the coloured cards others marked respectively I., II., and III. This we continued for another ten weeks, but entirely without success. I was rather disappointed at this; as, if it had succeeded, the plan would have opened out many interesting lines of inquiry. Still, in such a case one ought not to wish for one result more than another, as of course the object of all such experiments is merely to elicit the truth; and our result in the present case, though negative, is interesting. I do not, however, regard it as by any means conclusive, and should be glad to see it repeated. If the result proved to be the same, it would certainly imply very little power of combining even extremely simple ideas.

I then endeavoured to get some insight into the arithmetical condition of the dog's mind. On this subject I have been able to find but little in any of the standard works on the intelligence of animals. Considering, however, the very limited powers of savage men in this respect; no Australian language for instance, containing numerals even up to four; and no Australian being able to count his own fingers even on one hand—we cannot be surprised if other animals have made but little progress.

Leroy, who, though he expresses the opinion that 'the nature of the soul of animals is unimportant,' was an excellent observer, mentions a case in which a man was anxious to shoot a crow. 'To deceive this suspicious bird the plan was hit upon of sending two men to the watch-house, one of whom passed on while the other remained; but the crow counted, and kept her distance. The next day three went, and again she perceived that only two retired. In fine, it was found necessary to send five men to the watch-house to put her out in her calculation. The crow, thinking that this number of men had passed by, lost no time in returning.' From this Leroy inferred that crows could count up to four. Upon this point Mr. Howard Saunders has furnished me with the following note:—'A short-toed eagle (*Circaëtus Gallicus*), was hovering suspiciously and out of gun-shot above her nest in a large cork-tree under which I and two of my Spanish *cazadores* were standing, partially, but not carefully, concealed. One was sent away, when the eagle, after accompanying him for a short distance, returned to her post of observation. After an interval I left also, when the manœuvre was repeated, but no sooner had the bird watched me well off the ground than she unhesitatingly pitched on her nest, affording an easy shot to the third man.'

An interesting consideration rises with reference to the number of the victims allotted to each cell by the Solitary Wasps. *Ammophila* considers one large caterpillar of *Noctua segetum* enough; one species of *Eumenes* supplies its young with five victims, another ten, fifteen, and even up to twenty-four. The number appears to be constant in each species. How does the insect know when her task is fulfilled? Not by the cell being filled, for if some be removed, she does not replace them. When she has brought her complement, she considers her task accomplished, whether the victims are still there or not. How then does she know when she has made up the number twenty-four? Perhaps it will be said that each species feels some mysterious and innate tendency to provide a certain number of victims. This would under no circumstances be any explanation, but it is not in accordance with the facts.

In the genus *Eumenes* the males are much smaller than the females. Now in the

hive-bees, humble-bees, wasps, and other insects, where such a difference occurs, but where the young are directly fed, it is, of course, obvious that the quantity can be proportioned to the appetite of the grub. But in insects with the habits of *Eumenes* and *Ammophila*, the case is different, because the food is stored up once for all. Now it is evident that if a female grub was supplied with only food enough for a male, she would starve to death; while if a male grub were given enough for a female, it would have too much. No such waste, however, occurs. In some mysterious manner the mother knows whether the egg will produce a male or female grub, and apportions the quantity of food accordingly. She does not change the species or size of her prey, but if the egg is male, she supplies five; if female, ten victims. Does she count? Certainly this seems very like a commencement of arithmetic. At the same time it would be very desirable to have additional evidence how far the number is really constant.

Considering how much has been written on instinct, it seems surprising that so little attention has been directed to this part of the subject. One would fancy that there ought to be no great difficulty in determining how far an animal could count, and whether, for instance, it could realise some very simple sum, such as that two and two make four.

But when we come to consider *how* this is to be done, the problem ceases to appear so simple. We tried our dogs by putting a piece of bread before them, and preventing them from touching it until we had counted seven. To prevent ourselves from unintentionally giving any indication, we used a metronome (the instrument used for giving time when practising the pianoforte), and to make the beats more evident we attached a slender rod to the pendulum. It certainly seemed as if our dogs knew when the moment of permission had arrived; but their movement of taking the bread was scarcely so definite as to place the matter beyond a doubt. Moreover dogs are so very quick in seizing any indication given them, even unintentionally, that, on the whole, the attempt was not satisfactory to my mind.

I was the more discouraged from continuing the experiment in this manner by an account Mr. Huggins gave me of a very intelligent dog belonging to him. Cards were placed on the ground, numbered from 1 to 10; and a question being then asked: the square root of 9 or 16; or such a sum as $\frac{6+2-3}{5}$, Mr. Huggins pointed consecutively to the cards, and the dog backed when he came to the right one. Now Mr. Huggins did not *consciously* give the dog any sign, yet so quick was the dog in seizing the slightest indication, that he was able to give the correct answer. This observation seems to me of great interest in connection with the so-called 'thought-reading.' No one, I suppose, will imagine that there was in this case any 'thought-reading' in the sense in which this word is used by Mr. Bishop and others. Evidently the dog seized upon the slight indications unintentionally given by Mr. Huggins. I have brought this question before the Section in hope of inducing others with more leisure and opportunity to carry on similar observations, which I cannot but think must lead to interesting results.

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3. *On the Development of the Food-fishes at the St. Andrews Marine Laboratory.* By Edward E. Prince.

After referring to the literature of the subject and the incomplete state of our knowledge of the embryology of the osseous fishes of British seas, the author proceeded to give details of the deposition of the ova in certain species. Of about twenty forms, deep-sea and littoral, studied in the St. Andrews Marine Laboratory, attention was specially directed, chiefly on account of their economic importance, to the six following species, viz., *Gadus merlangus*, *G. morrhua*, *G. æglefinus*, *Trigla gurnardus*, *Pleuronectes flesus*, and *P. limanda*. Amongst these species, the ova of which are pelagic, differences in the manner and duration of deposition probably obtain. Thus the extrusion of ova in the Pleuronectidæ would appear to be more rapid and continuous than in *Trigla gurnardus* and the gadoids, in which the act of spawning is, it would seem, intermittent and prolonged. The examina-

tion of the spermatozoa reveals no marked differences, except that of size, the usual enlarged head and motile filament being distinguishable in all.'

The ova treated of in this paper are extremely buoyant, and float, in the living and healthy condition, as minute transparent globes, near the surface of the water. Loss of buoyancy and transparency, as Professor McIntosh's observations[1] have shown, indicate an unhealthy or non-living state. After the germinal vesicle, readily seen in immature intra-ovarian eggs, is no longer distinguishable, the ovum consists of (*a*) a central globular deutoplasm, destitute of oil-globules in British Gadoids and flat fishes, but exhibiting in *T. gurnardus* a single, pale salmon-coloured oil-globule like that of *Brosmius americanus*, a noteworthy American Gadoid; (*b*) a cortical protoplasmic film, containing minute vesicles and granules; (*c*) a thin external hyaline capsule, separated from the vitelline mass by a narrow space, the 'breathing chamber' of Newport. The capsule is tough, structureless, slightly resilient, free from punctures or striations, and varies in thickness in different species. Thus in *P. limanda* its thickness is ·0001 in.; *P. flesus*, ·000125 in.; *G. morrhua*, ·00025 in.; and *T. gurnardus*, ·0005 in. One aperture, the micropyle, pierces the capsule, and in the species here treated of, it presents the usual simple features, being generally situated, excentrically, in the lowermost (germinal) segment of the ovum. After fertilisation, the ovum becomes clearer and more tense, and a movement of the superficial protoplasm towards the germinal pole commences. The surface of the deutoplasmic globe presents at this time a corrugated appearance, but the areas of transference were less definite than Ryder indicates.[2] The cortical protoplasm collects as a germinal disc or cap, which segments in the usual manner and performs a retrogressive movement spreading once more over the yelk, and epibolically enveloping it. Irregularity in cleavage is common, resulting in asymmetry of the disc. This feature was especially noticeable in the two reniform cells of the ovum of *T. gurnardus*, after the first cleavage, but symmetry was restored when the polycelled stages were reached. In some forms the blastodermic scutum presents a more acuminate central promontory than in others. It is acute in *G. merlangus* and *S. fario* (Oellacher), less so in *G. morrhua* and *T. vipera* (G. Brook), quite obtuse in *G. æglefinus, T. gurnardus, P. flesus, Motella mustela* (Brook), and *Perca fluviatilis* (Lereboullet). The inwardly-directed point of the scutum forms the snout of the embryo, and a thickening extends outwards (radially) which indicates the developing trunk. The cephalic swelling, the neurochord, the mesoblastic muscular plates, develop in the usual way, and between the latter the notochord is pushed up.

The differentiation of the notochord is coincident in many species with the closure of the blastopore, e.g., *G. merlangus, G. morrhua, P. flesus,* and *P. limanda*; but in *T. vipera* and *M. mustela* it precedes, while in *G. æglefinus* and *T. gurnardus* it succeeds the closure by an interval of one or two days. A like variation obtains in the time of the appearance of Kupfer's vesicle.

Several features were next referred to as probably diagnostic, and therefore worthy of note, viz., the formation of a protoplasmic reticulation upon the surface of the yelk in *P. limanda* on the eighth day; the appearance of one or more colourless enucleate stellate structures, on the yelk surface beyond the lateral margin of the embryo, in *G. merlangus* on the seventh day. This latter structure assumes the form of a 'bone-corpuscle,' and was observed in no other species studied at St. Andrews. *T. gurnardus*, previous to the act of emergence, exhibits on the yelk-surface many minute protoplasmic elevations from which pseudopodial processes protrude. Each is isolated and exhibits a nucleus and nucleoli.

Pigment appears to have a diagnostic value in the case of Teleostean embryos, though the study of a very extended series of forms can alone establish the contention that it affords a reliable means of identification. Pigment appears earliest in *P. flesus*, and as described by Professor McIntosh,[3] is 'of a peculiar pale olive-brown (brownish-yellow by transmitted light), whereas in *P. limanda* it is of a more dis-

[1] *Report of H.M.'s Trawling Commission*, 1884, pp. 31–33.

[2] *United States Fish Commissioners' Report*, 1882. 'Embryography of Osseous Fishes,' Pl. I. figs. 6 and 7.

[3] *Second Annual Report Scottish Fishery Board.* Appendix F. p. 47.

tinctive yellow colour, in fact, a rich amber shade. In the latter species the spots appear on the seventh day after deposition, and rapidly extend from the dorsum almost to the caudal termination. In neither species, however, is the yelk-surface pigmented. *G. merlangus* shows no colouration till the eighth day, when numerous pale yellow spots, having a greenish tinge, appear confined chiefly to the dorsum, but soon extending over the whole trunk, the embryonal fin and the yelk-surface. The two remaining Gadoids exhibit black pigment only. It appears in *G. morrhua* on the seventh day (in a series which emerged from the ovum on the ninth day); but in *G. æglefinus* (which emerged on the twentieth day) it was visible on the eleventh day. The spots are at first amorphous, and numerous on the dorsum; but they rapidly extend over the tail, and become densely aggregated in the mesenteric region. The 'shoulder,' above the pectoral fins is also thickly pigmented. The embryo of *T. gurnardus* exhibits scantily distributed pigment, at first of a pale sea-green tint, intermingled, two days later, with yellow corpuscles and minute black spots. This colouration also appears in the protoplasmic investment of the oil-globule present in this species.

In the development of the sense-organs, &c., no special features were observed in the species studied. The embryo remains quiescent in the lower segment of the ovum until the cardiac pulsations commence. The rhythmical movement of the heart, many days prior to the existence of a hæmal circulation, or indeed of a hæmal fluid, is an interesting physiological phenomenon, and is coincident generally or slightly subsequent to the appearance of pigment in the epiderm. It is noteworthy that the first motion of the embryonic trunk (in each series of ova studied in the St. Andrews Marine Laboratory) took place on the day preceding liberation, when the tail, now free from attachment to the yelk, is flexed and relaxed violently. These erratic movements probably assist in facilitating extrusion from the capsule. The newly-emerged embryos are extremely sensitive and delicate, and swim in a reversed position for some time. Neither mouth nor anus is developed, but branchial arches are indicated, though the clefts are incomplete. The Pleuronectidæ are even more rudimentary than the newly-hatched Gadoids, and exception must be taken to the statement of Mr. G. Brook[1] that the Gadidæ differ from all other teleosteans in the late formation of the anus. The oral aperture usually appears at the end of the first week, and one or two days later the proctodæum can be detected. The formation of large sub-epidermal spaces, especially in the cephalic region of the embryo, is a remarkable feature, the skin, as Ryder remarks,[2] 'is lifted off, perceptibly, from the underlying structures,' and the interspace formed is filled with a transparent plasma. Young embryos a week old assume a very grotesque appearance on account of this anterior enlargement. Simultaneously the epiderm becomes nodulate, the eyes are deeply pigmented, and a simple arterial and venous circulation is established. The deutoplasm continues visibly to decrease, though there is no yelk-circulation in the species here considered.

With regard to the conditions of temperature, so important in these investigations, the attempt is made in the St. Andrews Marine Laboratory to keep the water in the tanks at the same temperature as the sea outside. The laboratory is almost completely surrounded by sea-water, and by a continuous supply from St. Andrews Bay, a constant circulation is maintained through the tanks, which is highly favourable for rearing young teleosteans. It was thus possible to keep the temperature at about 40° F. during March and April, rising to 48° and 50° F. in May and June, these being the months during which the species here considered were reared and studied.

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4. *On the Nest and Development of* Gastrosteus spinachia *at the St. Andrews Marine Laboratory.*[3] *By* Edward E. Prince.

This paper was chiefly a record of observations made upon the nidification and development of the ova of this common Teleostean in the St. Andrews Marine

[1] *Linnæan Society Journal*, vol. xviii. p. 304.
[2] *United States Fish Commissioners' Report*, 1882, p. 530.
[3] Published *in extenso* with figures in the *Ann. Nat. Hist.* for December 1885.

Laboratory. It was shown that the size of the nest depended upon the character of the materials employed and upon the number of female fishes resorting to a single nest; and it was pointed out that the dimensions (5–8 centimetres) named by Professor Möbius were often very much exceeded. If the fronds of the larger Algæ (Fuci &c.) be chosen, the nest is pear-shaped or cylindrical, and of greater capacity (length 8–10 inches, and diameter, widest part, 5–6 inches) than when more minute seaweeds (*Ceramium*, *Corallina*, &c.) are selected. In the latter case the nest is more spherical, and 3–5 inches in diameter. Compactness is secured by binding threads upon the outside, which are often so disposed as to form a reticulation, the crossing cords enclosing lozenge-shaped spaces. The substance of the cords is a secretion which exudes from the epithelial cells of the sinuous urinary canals. The cells present (as transverse sections show), at the latter end of April and during May and June, a swollen appearance. The secretion is not merely a semi-solid plasm; but, before reaching the spacious ureters at the external border of the kidney, assumes a marked funicular character. It is colourless, opalescent when freshly extruded, and of mucilaginous consistency. Möbius determined its nitrogenous composition: carmine stains it deeply, it becomes opaque in spirit, and after exposure to sea-water (for 2–3 days) it turns transparent grey or dirty white. It is thus a form of Mucin peculiarly modified, possessing extraordinary elasticity, and it is stored up in the urinary bladder. This structure is disproportionately developed, pyriform, and describes a double curve, posterior to the cervix, before debouching behind the genital pore into a urino-genital sinus forming the posterior portion of the cloacal depression, into which the anus also opens. The weaving operation as seen in the tanks of the laboratory was referred to, and the structure of the cords then described. Each cord (·0046–·0051 in. in diameter) consists of several strands (·0008–·00092 in. in diameter), and these constituent threads, again, are made up of fine homogeneous filaments adhering in parallel order. The nest is so constructed by the male as to leave numerous irregular chambers, in each of which the female deposits some ova. The ova are extremely ellipsoidal, disproportionately large, and the soft tenacious capsule assisted by an ovarian plasm causes them to adhere strongly together. If torn asunder facets or scars on the capsule mark the points of attachment to adjacent ova. The colour is a delicate pale green, which soon changes to the characteristic translucent amber tint. The hyaline capsule has a thickness of ·0013 in., and is separable into 20 to 30 lamellæ. It is minutely punctured, the pits being arranged in parallel rows. A large mass of loosely aggregated oil globules occupies the vegetative pole. Two hours after fertilisation the cap is completed at the germinal pole, and segmentation presents the usual features, though it is comparatively slow. On the fourth day the nuclei of the periblast appear, and by the eighth day the embryonal thickening is well marked, epiboly having proceeded over two-thirds of the yelk surface. At the close of the same day the mesoblastic muscular plates are well-defined. Closure of the blastopore is effected on the twelfth day, and soon after Kupfer's vesicle is distinguishable. By the seventeenth day the heart assumes the campanulate shape; and the protovertebræ are marked off from the otocystic region to the caudal plate. A hæmal circulation is visible, though languid, on the nineteenth day, and by simple lacunæ hollowed out of the yelk-cortex spacious passages are formed, and a yelk circulation, by the twentieth day, is in vigorous action. The young fish shows movement on the nineteenth day, and the first embryos emerge on the twenty-fifth day. The centrally-situated ova develop more slowly, many of these not hatching until the fortieth day. The water of the tanks varied from 41° F. in May to 50° or 51° F. early in June, and the general conditions of the laboratory being unusually favourable for the development of ova of marine fishes, the phenomena observed may be taken as almost normal.

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5. *On the Reproduction of the Common Mussel* (*Mytilus edulis, L.*) *By* JOHN WILSON.

The common mussel is completely diœcious, and is peculiar in having the sexual elements developed in the mantle as well as in a wedge-shaped central

mass. Professor McIntosh has pointed out that the mussel reaches full reproductive maturity in April, and that there is a gradual disappearance of the ova or spermatozoa during June and July, until, in the latter month, most examples are quite empty. The female generative organs are almost invariably redder than the male, and the groups of sperm-sacs are more prominent than the ovigerous masses. When an incision is made in the fully ripe male or female organ, a creamy fluid issues, holding respectively immense numbers of spermatozoa or ova. In the ovary the ova are surrounded by a transparent hyaline investment, and, when fully ripe, the germinal area and germinal spot are lost to view, the vitellus becoming densely granular. The genital canal is readily seen, and microscopic sections show it to be clothed internally with ciliated epithelium. Natural fertilisation in all likelihood takes place in the surrounding water. Artificial fertilisation is easily accomplished. A piece of tissue containing spermatozoa is minced in a watch-glass with sea-water, and a little of the milky liquid decanted into another glass. Into the latter is then poured a little liquid containing ova procured in the same way. The glass is kept cool, and in half an hour the milkiness is removed from the liquid by repeated washings, and particles of débris sucked up by a fine pipette. Each ovum has now a considerable number of spermatozoa attached to it, and their wriggling causes it to rotate. In about four hours the clear polar or direction-cell appears. Decreasing vigour and changes of temperature cause conflicting results as to the time certain developmental stages are reached. Fertilisation so late as August 1 was partially successful. The writer's earliest attempt (and it was the most successful) was made in the beginning of June. The first segmentation takes place immediately after the appearance of the polar cell, resulting in a larger segment (macromere) and a smaller (micromere). Repeated budding of the micromere takes place, and in six or seven hours the embryo assumes its most irregular form. Thereafter it is gradually reduced to a more regular shape, and in ten hours the brownish granular contents have disappeared. In fifteen or eighteen hours the shape is almost spherical, and the contour is broken by the projecting part of what is probably the still undivided macromere. The free edge of this body is crenate. The existence of a central cavity can now be made out, the polar cell still persists in many cases, and the embryo rotates by means of minute cilia which seem to cover the greater part of its surface. Two examples (of distinct series), forty-three hours old, were characterised by having, besides the minute cilia, in the one case one strong cilium at least as long as the diameter of the embryo; in the other by two cilia somewhat longer. In both forms there were features indicating approaching differentiation of structure. Embryos have been kept alive for four days, but not in a healthy condition.

The very youngest forms taken by the tow-net from the surface of St. Andrews Bay, where, in July and August, they abound in great numbers, have the body wholly enveloped in a transparent shell, and the various organs are still very rudimentary. By the time they sink to the bottom, the foot, byssus gland, revolving otoliths, liver, and gill-papillæ are well seen. The foot, which is ciliated at the tip, adhesive, and extremely extensile, is the means of active locomotion. Amongst the smallest examples of a previous season, many not more than one-eighth of an inch in length contained in their tissue either ova or spermatozoa, presenting no appreciable difference from those of the adults. They were probably not more than a year old.

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6. *On the Modification of the Trochal Disc of the Rotifera.* *By* Professor A. G. Bourne, *D.Sc., F.L.S.*

It is now a generally accepted theory that this structure is the homologue of the ciliated bands of the larvæ of Echinoderms, Chætopods, Molluscs, &c., and of the tentaculiferous apparatus of Polyzoa and Gephyrea, and is often termed in common with these a 'velum.' This velum presents itself in various stages of complexity. It is found as a single circum-oral ring (*Pilidium*), as a single præ-oral ring (Chætopod larvæ), or as a single præ-oral ring, co-existing with one or

more post-oral rings (Chætopod larvæ, Holothurian larvæ). We may here assume that the ancestral condition was a single circum-oral ring associated with a terminal mouth and the absence of an anus, and that the existence of other rings posterior to this is an expression of metameric segmentation, *i.e.*, a repetition of similar parts. With the development of a prostomiate condition a certain change necessarily takes place in the position of this band; a portion of it comes to lie longitudinally, but it may still remain a single band, as in the larvæ of many Echinoderms. How have the other above-mentioned conditions of the velum come about? How has the præ-oral band been developed? Two views have been held with regard to this question. According to the one view, the fact whether the single band is a præ-oral or a post-oral one depends upon the position in which the anus is about to develop. If the anus develops in such a position that mouth and anus lie upon one and the same side of the band, the latter becomes præ-oral; if, however, the anus develops so that mouth and anus lie upon opposite sides of the band, the band becomes post-oral. If we hold this view, we must consider any second band, whether præ- or post-oral, to arise as a new development. The other view premises that the anus always forms so as to leave the primitive ring or 'architroch' post-oral, *i.e.*, between mouth and anus. Concurrently with the development of a prostomium this architroch somewhat changes its position, and the two lateral portions come to lie longitudinally; these may be supposed to have met in the median dorsal line, and to have coalesced, so as to leave two rings, the one præ-oral (a 'cephalotroch'), the other post-oral (a 'branchiotroch'). This latter may atrophy, leaving the single præ-oral ring, or it may become further developed and thrown into more or less elaborate folds.

The existing condition of the trochal disc or velum in the Rotifera seems to the author to bear out the latter view as to the way in which the modifications of the velum may have come about; further, these results may be well compared with those recently obtained by Selenka in the Sipunculids. The trochal disc in the Rotifera in its simplest condition forms a single circum-oral ring, as in *Microcodon.* This simple ring may be thrown into folds, so forming a series of processes standing up around the mouth; this is the condition in *Stephanoceros.* There are, however, but few forms presenting this simple condition, and it must be remembered that the evidence for the assumption here made is at present inconclusive. This band may, while remaining single and perfectly continuous, become prolonged around a lobe overhanging the mouth—a prostomium. This condition occurs in *Philodina*; the two sides of the post-oral ring do not meet dorsally, but are carried up, and are continuous with the row of cilia lining the 'wheels.' There is thus one continuous ciliated band, a portion which runs up in front of the mouth. This condition corresponds to that of the Auricularian larva. The folding of the band has become already somewhat complicated. We have only to go a slight step further and the prostomial portion of the band becomes separated as a distinct ring, a cephalotroch. We find such a stage in *Lacinularia*, where both cephalotroch and branchiotroch remain fairly simple in shape. In *Melicerta* the branchiotroch is becoming thrown into folds. Lastly, we find that in such forms as *Brachionus* the cephalotroch becomes first convoluted and then discontinuous, and further it may become so reduced as to be represented only by a few isolated tufts. In such a form as *Lindia* the branchiotroch has become reduced to be two small patches at the sides of the head.

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7. *On Budding in the Oligochæta.* *By* Professor A. G. Bourne, *D.Sc., F.L.S.*

The author, while working at the Naididæ with the view of preparing a monograph upon the group, has been enabled to make a series of observations upon the exact method of formation of the bud. The observations here described were made upon *Nais* (*Stylaria*) *proboscidea*, and there appears to be some variation in the process, as it occurs in different genera or species. In *N. proboscidea*, when budding is about to commence, a slight thickening of one of the septa which separate one cœlomic segment from another occurs. This thickening increases,

the body-wall in the region thickens, and an actual budding region is here formed. This new region elongates and presents a solid appearance. The alimentary canal grows in this region, but the newly-formed portion is at first unpigmented, and may still be detected at a much later period by its lighter colour; its lumen remains, however, all the time, and a continuous line of fæcal matter may be observed.

This budding region divides into two portions. The anterior portion develops numerous setæ, and gives rise to an indefinite number of segments which form the tail of the old worm; the posterior portion develops four pairs of ventral setæ. This development taking place from before backwards, and subsequently at its anterior region, the characteristic proboscis is developed, and the two individuals separate. The budding region usually forms between the 25th and 26th segments, so that the 26th segment of the parent worm becomes the 5th segment of the posterior daughter worm, the four anterior segments of this worm never presenting dorsal setæ. This condition, moreover, obtains in all the individuals, whether sexual or otherwise, of *Nais proboscidea*, i.e., there are four anterior modified (cephalized) segments. The number of such segments varies in different species of the group.

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8. *Demonstration of a new Moneron. By* Professor D'Arcy W. Thompson.

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9. *On the Blastopore and Mesoblast of Sabella. By* Professor D'Arcy W. Thompson.

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10. *On the Annelids of the Genus* Dero. *By* E. C. Bousfield.

The annelids belonging to the genus *Dero* are allied by most of their external characters to the *Naides*, but are distinguished from them—

1. By the absence of eyes.
2. By the absence of corpuscles from the perivisceral fluid.
3. By the termination of the body in a wide membranous expansion bearing four branchial processes.

This expansion, or branchial area, is essentially a prolongation and opening out of the posterior part of the intestine, and is covered on its non-ciliated surface by the general integument of the body. It is highly contractile, this property being due to the presence of numerous stellate muscle-cells between the respiratory and epidermal walls. Between these walls also run the blood-vessels, the arrangement of which is in this part of their course much modified from the type which characterises the genus *Nais*. The abdominal vessel runs along the middle of the branchial area and divides at its termination into two branches, which run round the area, giving off looped branches to the branchial processes (one to each) and also branches which cross the area obliquely. The branches of each side unite in a common trunk, and the two trunks together form the dorsal vessel. The branchial processes are elevations of the ciliated surface of the area, and as already stated contain a looped blood-vessel, this being surrounded by a hollow cone of muscular elements, by means of which the processes are lengthened or shortened at the will of the animal.

Very various accounts are extant with respect to the number of the processes, but in no case do more than four arise from the floor of the area, and sometimes two supplementary ones of much smaller size on the margin of the latter, where it joins the dorsal surface of the body. Wherever a greater number has been described than three pairs, it is due to the fact that the expanded edges of the branchial area, seen in profile, or perpendicularly, have been mistaken for additional ones, and to arrive at a correct estimate it is absolutely necessary to examine the animal without any pressure whatever. The form of the processes varies in different species. It is cylindrical in *D. Perrieri* and *palpigera*; flattened-cylindrical in *latissima*; foliate, with rounded apices, in *philippinensis, limosa,* and *obtusa*;

and in *acuta* the outline is that of a long isosceles triangle, with the sides about two to three times the length of the base.

The chief works on the subject are as follows:—Müller, 'Die Würmen,' &c., 1775 (*digitata*); Rösel, 'Insecten-Belustigung,' 1761 (*palpigera*); D'Udekem, 'Bull. Ac. Roy. Brux.' 1855 (*obtusa* and *digitata*); Semper, 'Arbeit. Zool. Inst. Wurzb.' 1877 (*philippinensis* and *Rodriguezii-palpigera*); Leidy, 'American Naturalist,' 1880 (*limosa*); Vejdovsky, 'System und Morphologie der Oligochaeten,' 1884 (the whole subject); Perrier, 'Arch. de Zool. Experiment,' 1872 (*obtusa ?*). I have not found it possible to identify Müller's species as yet. His figures have been copied by all who have given figures of *D. digitata*, and no trustworthy one exists. Recent writers have only recorded the fact of having found it, or given a verbal description. Perrier's *D. obtusa* is a new species, and I have named it *D. Perrieri* for convenience of reference. *D. latissima* is described for the first time. *D. acuta* is also new. It is probably one of the *two* species figured as *digitata* by Müller. *D. palpigera* of Grebincky was first figured by Rösel (*loc. cit.*), and redescribed as *D. Rodriguezii* by Semper. The latter also described *D. philippinensis*, but did not figure it, so that the identification of it is doubtful; a remark which also applies to *limosa*, of which only a small outline figure is extant. Further investigation may prove that the species which I have described and figured under those names are new British species, in which case all the species included in my diagnosis, except *palpigera*, are British, and to be found near London. Their number will probably be added to as time goes on.

The following is a complete list of known species:—

1. *Dero obtusa.* The processes short, stunted, flat, four in number.
2. *Dero Perrieri.* Four cylindrical processes, well developed.
3. *Dero latissima.* Four long flattened cylindrical processes; the branchial area expanded into two large wings.
4. *Dero palpigera.* The branchial area terminating in two long, non-ciliated tentacles. The branchial processes four long cylindrical, and two shorter supplementary ones.
5. *Dero limosa.* Four foliate processes, of considerable length; two short supplementary cylindrical ones springing from the angles of dorsal lip.
6. *Dero philippinensis.* Characters as *limosa*, but the supplementary processes springing from a common root.
7. *Dero digitata.* The last segment terminating in two very long processes; four branchial processes.
8. *Dero acuta.* Characters as *limosa*, but the four branchial processes long and triangular, and the area convex in full expansion, with everted edges.

The foregoing descriptions apply to the asexual form; I have only seen the sexual form of the second and third species named.

11. *On some little known Fresh-water Annelids.* By E. C. BOUSFIELD.

12. *On the Coloration of the Anterior Segments in the Malanidæ.* By Professor ALLEN HARKER, *F.L.S.*

13. *Systématique du genre Polygordius.* By JULIEN FRAIPONT.

14. *On some of our Migratory Birds, as first seen in Aberdeenshire.* By JAMES TAYLOR.

Some notes on the first arrival of our summer visitants among birds, so as to give some idea of spring migratory movements. The migration of birds and its causes have occupied the thoughts of eminent ornithologists. It is not our purpose to understand the principle of instinctive movements, but sufficient to say that

many of these may be traced to the laws which regulate the movements of animal economy and directed by their constitutional impulses, as one class of birds seeks more genial climates before the approach of winter, and where their food supplies can be obtained, and on the other, when the storms and frost of winter have been removed, those wandering world-wide citizens find fields and pastures new. It is only their first appearance that can be noticed and noted with care, and thus form an index of their certain movement, and that times and season are not things of chance. Although they make their appearance under different surroundings, their departure is not so easily noticed because in some cases they leave one by one, or in small flocks, and if like the lapwings, the birds old and young gather from July to October into larger and larger flocks of several hundreds, and perhaps seen to-day and to-morrow all have left, without any apparent cause either of food or climatic conditions. Their spring and autumn movements are like their call-notes, breeding-notes, or song-notes; they are constitutional, and manifest themselves when required. We might as well say it is instinct that causes a flower to bloom and assume its natural and inherent colours; the impulses are constitutional, and manifest themselves from earliest life; they are not simple but compound, connected with their physical and procreative functions relating to each animal's life-history and worked into their brain system, and thus become reproduced, in successive generations it becomes stereotyped, so that in most cases external influences have little or no effect, either to cause or retard these migratory movements. True, these outward conditions may quicken or lengthen these movements, but they can neither stop nor arrest them, and even by their destructive influence lessen their number, as under favourable conditions may increase them. And this is true in migratory birds in all parts of the world when their lines of migrations can be traced. Many years ago, when passing through these migratory lines in Arctic seas, we have observed them in their long journeys to their breeding and feeding grounds, both in spring and on their return south in autumn, from the small red-polled linnets, *Linaria borealis.* Gould, the snow bunting, *Plectrophanes nivalis,* Linn., and the Lapland lark bunting, *P. Lapponica,* Seb., and also the large birds both land and sea, such as the peregrine falcon, the cormorant, *Phalacrocorax carbo,* Steph. It is a well-known fact that many of the smaller land birds are caught in the rigging of ships, and some of the larger if the storm of snow or rain with frost continues sufficiently long, the cause of which is frozen ice or snow that accumulates on their feathers so much increasing their weight that flight becomes impossible, and they perish and vast numbers die. Again, in aquatic birds the cause is different from that. During a snow storm they lose the ice-coat, from whatever cause they from their low mode of flight under such often travel far on the land, and strike against objects and thus perish, to be understood from the accounts of lighthouses and ships. In our temperate climate one of the chief causes of delay and loss of life among migratory birds is rain and wet misty fog, the one a storm of wind and rain, the other a long continuance of dull foggy mist when almost everything is invisible, the birds become weighted by the accumulation of water on their feathers, so that they find it impossible to continue their flight, sink down from exhaustion in the sea, perish on the land, die from exhaustion and want of food. One fact well known is, that during foggy weather the young jackdaws and hooded crows are caught in large numbers, because when once wetted with dew they cannot rise. It is often by this means that the arrival of our migratory birds is delayed, but at the same time it is remarkable how little difference there is, taking one year with another. Climatic causes tend from accident to diminish their number rather than affect the regularity of their visits. Another point of equal importance is their departure, but the means of ascertaining it is more difficult, because some birds move in large bodies, while others move in small flocks. If these remarks give any interest to the subject of the arrival and departure of our migratory birds over the country, it in time will add much to our knowledge of their life-history and habits.

The Spring arrival of Birds in Aberdeenshire from 1855 *to* 1885.

House swallow, *Hirundo urbica*, Linn.

1855. May 10	1865. April 25	1876. April 28
1856. „ 14	1866. „ 25	1877. „ 17
1857. April 22	1867. „ 18	1878. May 4
1858. „ 25	1868. „ 29	1879. April 15
1859. „ 20	1869. „ 20	1880. „ 8
1860. May 7	1870. „ 19	1881. „ 20
1861. April 19	1871. „ 9	1882. „ 17
1862. May 1	1872. „ 30	1883. „ 13
1863. „ 5	1873. „ 17	1884. „ 25
1864. April 18	1875. May 1	1885. May 8

Chimney swallow, *Hirundo rustica*, Linn.

1855. April 6	1865. May 1	1875. April 10
1856. „ 10	1866. „ 16	1876. „ 18
1857. May 1	1867. April 27	1877. „ 10
1858. April 18	1868. „ 16	1878. „ 10
1859. „ 10	1869. „ 17	1879. May 3
1860. „ 20	1870. „ 27	1880. April 20
1861. „ 15	1871. „ 27	1881. „ 13
1862. „ 17	1872. „ 12	1882. „ 20
1863. „ 18	1873. „ 29	1883. „ 8
1864. May 3	1874. „ 23	1884. „ 15

Bank martin, *Hirundo riparia*, Linn.

1855. April 10	1865. April 17	1875. April 24
1856. „ 10	1866. „ 29	1876. „ 30
1857. May 5	1867. „ 18	1877. May 4
1858. „ 1	1868. May 1	1878. „ 10
1859. „ 7	1869. „ 10	1879. „ 5
1860. „ 22	1870. April 18	1880. April 28
1861. „ 20	1871. „ 30	1881. May 2
1862. „ 16	1872. May 4	1882. „ 4
1863. „ 4	1873. „ 5	1883. „ 10
1864. „ 10	1874. „ 16	1884. April 27

Common cuckoo, *Cuculus canorus*, Linn., first heard.[1]

1855. May 12	1865. April 22	1875. May 6
1856. „ 10	1866. May 4	1876. „ 4
1857. „ 6	1867. „ 3	1877. „ 3
1858. „ 1	1868. April 28	1878. „ 10
1859. April 28	1869. May 10	1879. „ 2
1860. May 7	1870. „ 6	1880. „ 1
1861. „ 5	1871. „ 5	1881. „ 7
1862. „ 4	1872. „ 10	1882. April 20
1863. „ 1	1873. „ 3	1883. „ 24
1864. April 23	1874. „ 1	1884. „ 30

Common swift, *Cypselus apus*, Flem.

1855. May 13	1858. May 16	1861. May 7
1856. „ 14	1859. „ 15	1862. „ 4
1857. „ 19	1860. „ 9	1863. „ 10

[1] The cuckoo is generally heard from three to five days earlier in the more inland woody districts than on the coast.

1864. May 7	1871. May 11	1878. May 20
1865. „ 10	1872. „ 23	1879. „ 17
1866. „ 17	1873. „ 14	1880. „ 3
1867. „ 5	1874. „ 17	1881. „ 19
1868. „ 8	1875. „ 10	1882. „ 7
1869. „ 10	1876. „ 8	1883. „ 10
1870. „ 13	1877. „ 4	1884. „ 20

Corncrake, *Crex pratensis*, Bechst., first heard.

1855. May 22	1865. May 4	1875. May 10
1856. „ 13	1866. „ 7	1876. „ 8
1857. „ 16	1867. „ 5	1877. „ 10
1858. „ 18	1868. April 26	1878. „ 16
1859. „ 9	1869. May 11	1879. „ 21
1860. „ 16	1870. „ 18	1880. „ 1
1861. „ 6	1871. „ 20	1881. „ 9
1862. „ 4	1872. „ 14	1882. „ 22
1863. „ 1	1873. „ 20	1883. „ 5
1864. „ 12	1874. „ 10	1884. „ 3

Crested lapwing, *Vanellus cristatus*, Meyer.

1855. March 2	1866. March 28	1877. March 10
1856. „ 19	1867. „ 10	1878. „ 2
1857. Feb. 19	1868. „ 18	1879. April 1
1858. March 13	1869. „ 14	1880. March 4
1859. „ 20	1870. „ 19	1881. Jan. 31
1860. „ 14	1871. „ 16	1882. March 10
1861. Feb. 20	1872. „ 27	1883. „ 17
1862. March 10	1873. „ 20	1884. Feb. 16
1863. Feb. 29	1874. „ 10	1885. March 10
1864. March 17	1875. „ 17	
1865. „ 7	1876. „ 18	

Supplementary Meeting.—ANATOMY.

1. *On the Connection of the Os odontoidium with the centrum of the axis vertebra. By* Professor D. J. Cunningham, *F.R.S.*

2. *On the Curvature of the Spine in the Fœtus and Child. By* Dr. Johnston Symington.

3. *On the Bronchial Syrinx of the Cuculidæ and Caprimulgidæ. By* Frank E. Beddard, *M.A., F.R.S.E.*

In this paper the author called attention to the bronchial syrinx hitherto only known in *Crotophaga* and *Steatornis;* it was found to be present in other cuckoos and goatsuckers, and showed a parallel series of modifications in both groups.

4. *Contributions to the Structure of the Oligochæta.*[1] *By* FRANK E. BEDDARD, *M.A., F.R.S.E.*

The present paper is a brief abstract of certain results obtained from the study of a number of different genera and species of earthworms lately received from New Zealand, the Philippine Islands, and the Cape Colony, through the kindness of Professor T. J. Parker, Mr. H. E. Barwell, and the Rev. G. R. Fisk.

(1) *Nephridia.*—Perrier has called attention to a remarkable inconstancy in the position of the nephridial pores in different genera of earthworms. In *Lumbricus* and other genera the external pores are placed near to the more dorsal pair of setæ in all the segments of the body; in *Anteus* the nephridial pores have a similar relation to the ventral pair of setæ; finally in *Pontodrilus* the nephridial apertures alternate in position from segment to segment, sometimes being placed by one of the dorsal, at other times by one of the ventral pair of setæ. These facts seem to indicate the typical presence in earthworms of two series of nephridia each corresponding to one of the two pairs of setæ—an hypothesis originally put forward by Lankester. Other earthworms besides *Pontodrilus* present this same alternation in the position of the nephridial pores; in two species of *Acanthodrilus* (*A. novæzelandiæ*, n. sp., *A. dissimilis*, n. sp.) the same series of facts were observed, but in these two species the dorsal and the ventral series of nephridia differed not merely in their position but also in their structure, which latter fact perhaps tends to still further support the hypothesis referred to above. The hypothesis of a single nephridium to each pair of setæ may be true enough for those earthworms where the setæ are disposed in pairs, but it is not sufficient to account for the relations of the nephridia described by Perrier in *Pontodrilus*. Here the setæ are in eight nearly equidistant longitudinal rows, other nephridial pores alternate not only from pair to pair of setæ but from seta to seta of each pair, seeming to be the remnant of a series of nephridia to each one of the setæ. That this is really the case is proved by the structure of another *Acanthodrilus* (*A. multiporus*, n. sp.) where the setæ are similarly disposed in eight longitudinal rows of single setæ, to each of which corresponds a nephridial tube and external orifice; in the anterior region of the body the nephridial tubules branch and open by a multitude of orifices forming a continuous ring round each segment between the setæ. The presence of more than a single pair of nephridia to each segment has already been noticed by Eisig in certain Capitellidæ, and the ducts have been stated by W. Fischer to branch in the same way that has been described in *Acanthodrilus multiporus*.

(2) *Spermathecæ.*—The spermathecæ of earthworms are in some species, as in *Lumbricus*, simple spherical sacs; in other species they are furnished with one or more diverticula. Sometimes the diverticula come to open into the exterior independent of the spermathecæ, as in certain species of *Perichæta*. In *Microchæta*, a large worm from the Cape Colony, there are no spermathecæ like those of other earthworms, but a number of minute pouches in four segments of the body, varying from one to four. These appear to correspond to the accessory pouches or diverticula of other species, and are placed close to the nephridia of their segments. They have in fact much the same relation to the nephridium as the diverticula of *Perichæta aspergillum* (Perrier) have to the spermathecæ, which is a further argument in favour of regarding the spermathecæ as modified nephridia. In *Acanthodrilus multiporus*, *novæzelandiæ*, and *dissimilis*, the spermathecæ are furnished with diverticula which vary in number, but are characteristic for the species. In every case these diverticula differ in their minute structure from the spermathecæ; and the fact that they are invariably packed with spermatozoa while the spermathecæ are as invariably devoid of spermatozoa indicates that their share in the process of fecundation differs from that of the spermathecæ.

(3) *Dorsal Blood-vessel.*—Dr. Vejdovsky has recorded the fact that in *Criodrilus* the dorsal vessel originates from two rudiments which at first form two distinct tubes and only subsequently coalesce. In certain earthworms the (presumably)

[1] See No. 238, *Proc. Roy. Soc.*

embryonic condition persists throughout life. In *Megascolex* and *Microchæta* the anterior section of the dorsal vessel is double, the two vessels fusing together where they traverse the mesenterics. In *Acanthodrilus novæzelandiæ* the dorsal vessel is double throughout the whole body, the two tubes becoming fused as in *Megascolex* at the mesenterics. In *A. multiporus* the primitive condition is more completely retained, since there are two dorsal vessels which remain distinct as far as the anterior extremity, and do not fuse where they traverse the mesenterics.

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5. *On the Cervical Vertebræ in* Balæna mysticetus, *&c.* *By* Professor STRUTHERS, *M.D., LL.D.*

Eight specimens of *Mysticetus* showed the bodies completely consolidated, even in the young state, with external indications. In some the first dorsal also united. Superior and inferior transverse processes slender and partially united externally. From his dissections of the soft parts in the Finners, the author could recognise the three stages of these transverse processes, the nerve-groove stage internally on the superior processes, externally on the inferior. The pedicles are much and variously atrophied.

Numerous specimens of *Globicephalus* showed the stages of consolidation. The rudimentary bodies, though very thin, have their epiphyses. In the young the line between the atlas and axis is distinct. In a young specimen the change of position of the transverse processes in relation to the neuro-central suture between the 8th and 10th dorsal vertebræ is well seen.

Dissections of *Beluga* and *Monodon* (Narwhal) showed the deficient bony transverse processes to be fully represented by fibrous cords and bands completing the rings.

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6. *On the Development of the Foot of the Horse.* *By* Professor STRUTHERS, *M.D., LL.D.*

Attention is called to the fact that the epiphysis of the rudimentary metacarpal and metatarsal bones is not situated at the upper or functional end, but, as in the case of the great metacarpal and metatarsal, at the lower end, here rudimentary. From this a ligament proceeds, expanding in a fascia. The position of this epiphysis is a significant fact, as a link in the chain of evidence of the descent of the horse. It had its use here in the hipparion and other forms which preceded the horse of the present day. The sections of the feet of young horses exhibited by the author also showed that the pastern bone, or first phalanx, has an epiphysis at the distal as well as at the proximal end, the distal epiphysis consolidating early. In the course of this paper, the author showed a specimen of polydactyly in the horse, the additional toe about one third the size of the main toe.

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7. *On the Development of the Vertebræ of the Elephant.* *By* Professor STRUTHERS, *M.D., LL.D.*

On the anterior vertebræ the neural arches meet below so as to shut out the bodies from forming any part of the spinal canal. The bodies are buried an inch deep by this mesial meeting of the neurapophyses. This diminishes backwards, the bodies at length rising to form part of the wall of the spinal canal. The vertebræ exhibited were from an elephant, said by the keeper to have been about thirty years of age.

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8. *On the Kidneys of Gasteropoda and the Renal duct of Paludina.* *By* W. B. BENHAM.

Section E.—GEOGRAPHY.

President of the Section—General J. T. Walker, C.B., R.E., LL.D., F.R.S.

[For General Walker's Address, see p. 1106.]

THURSDAY, SEPTEMBER 10.

The following Papers were read:—

1. *The Indian Forest School. By* Major F. Bailey, *R.E., F.R.G.S.*

It is only within the last twenty-five years that a special State Department has administered the Indian forests. The staff was at first composed of men who had received no professional education, but they were able to do all that was then needed, and they accomplished work of great value. As a result of their work the State became possessed of large forest areas, from which a permanent supply of produce had to be secured, and which had therefore to be managed systematically. But at this time nothing was known of systematic forestry in England or in India, and an arrangement was made in 1866 under which candidates for the Indian Forest Service were trained on the Continent. The arrangement then made with the French Government is still in force, but it has now been decided to undertake the instruction in England. Great progress has been made in Indian forestry, and this is mainly due to the professionally-trained men with whom the Forest Department has been recruited; but up to 1869 nothing had been done towards the education of the subordinate ranks. As work requiring professional skill became necessary over large areas, it was found that the 'divisions' must be broken up into a number of smaller executive charges under natives of the country, and that they must receive a professional education. In 1869 Mr. Brandis made proposals to organise the subordinate grades and to train men at the Civil Engineering Colleges, and several other attempts were made in the same direction, but without marked success.

In 1878 Mr. Brandis proposed to establish a Central Forest School, and his proposals were accepted by Government. The chief object of the school was to prepare natives of India for the executive charge of forest ranges, and to qualify them for further promotion, but it was hoped that it might ultimately be used to train candidates for the controlling branch. The chief forest officers of provinces were to select candidates and send them to be trained at the school, none but natives of India being admitted. A number of forests near Dehra Dun were grouped together as a training ground and placed under a separate conservator, who was also appointed director of the school; a board of inspection was also appointed. The first theoretical course was held in 1881, and courses have been held every year since then.

The present system is that the candidates, who must be in robust health, are selected by conservators of forests or by the director of the school. They must serve in the forests for at least twelve months before entering the school. Candidates for the ranger's certificate must have passed the entrance examination of an Indian University on the English side; candidates for the forester's certificate must have passed a lower examination. The course of training for these two classes extends over eighteen and twelve months respectively. Men who gain the certificates return

to their provinces, and are employed there. The course of instruction for the rangers' class embraces vegetable physiology, the elements of physics and chemistry, mathematics, road-making and building, surveying, sylviculture, working plans, forest utilisation, forest botany, the elements of mineralogy and geology, forest law and the elements of forest etiology. The course for foresters is much more simple. The preparation of manuals is in progress, and a library, museum, chemical laboratory, observatory and forest garden have been established.

The period of probation in the forest before entry into the school has a twofold object: firstly, to enable the theoretical course to be understood; secondly, to eliminate men who are unsuited to a forest life before time and money have been spent on their training. As a rule, the students are *employés* of the Forest Department, and they draw their salaries and maintain themselves while at the school; no instruction fees being charged. It would not at present be possible to get candidates whose maintenance and education are entirely paid for by their friends. Nine men who have left the school hold appointments worth from 125*l.* to 200*l.* a year, and this ought to draw eligible candidates. Conservators of forests say that the men trained at the school are markedly superior to their untrained comrades. The area of reserved forests has largely increased of late, and the prospects of the students are very good. During the session of 1884 there were forty-six students of all classes at the school, of whom eight were from Madras and seven from native States, the chiefs of which have been induced by the establishment of the school to take measures for the protection of their forests. The school has now been made an imperial institution, and this is a great advantage in every way. The expenses of the school in 1884 are said to have been 1,911*l.*

2. *Brazil.* *By* Colin Mackenzie, *F.R.G.S.*

The author gave an account of the physical geography of Brazil, of its resources and inhabitants. He contrasted the vast area of the country and its scant population, and said that if peopled as densely as Europe it would hold five hundred million souls instead of ten millions, as at present.

3. *On the Progress of African Philology.* *By* R. Needham Cust, *F.R.G.S.*

Taking Dr. Latham's paper on the subject, read at the meeting of the British Association at Oxford in 1847, as a starting-point, Mr. Cust showed how, during the last thirty-eight years, African philology, or linguistic geography, had extended to a marvellous degree, and, under the impetus given to the study of African languages by missionaries and travellers, new additions were being made every year to our knowledge.

4. *On the Changes which have taken place in Tunis since the French Protectorate.* *By* Lieut.-Colonel R. L. Playfair.

The author did not attempt to give a history of the events which led to the treaty of the Kasr-es-Saeed, by which the Bey lost his independence, and the actual government of the country became vested in the French Resident-General. After a few remarks on the manner in which the French are in the habit of governing their colonies, and the disfavour in which the foreign element is held, he bore his willing testimony to the important work of civilisation and improvement which is now being carried on in Tunis. He alluded to the fact that he had been the first foreigner to pass through the celebrated Khomair country in 1876, when it was simply a blank space on the maps then existing, and when neither private travellers nor Beylical officials were permitted to cross its frontiers.

He again visited this country last year, and traversed nearly the same ground, but on this occasion over admirably constructed carriage roads, passing from the Algerian frontier to Ain-Draham, a military station in the centre of the Khomair mountains, and thence down to the valley of the Medjerda through which now

runs a railway from Souk Ahras in Algeria to Tunis. He passed several important Roman cities, such as Simittu Colonia at the famous quarries of Numidian marble, and Bulla Regia, near the station of Souk-el-Arba. He visited El Baja on both occasions, and found it, on the former, a picturesque but fever-stricken town, and on the latter, clean and healthy, with the old Byzantine citadel transformed into modern French barracks.

At Tunis itself good roads are being constructed, and a modern French town is being built between the native city and the lake. But the picturesque Arab bazaars, which are a never-ending source of delight to the traveller, are quite untouched. Land is being rapidly brought under cultivation, taxes are being reduced or abolished, and a very important measure of reform is about to be effected, based on the famous Torrens Act, by which real property will become as easily transferable as a bank share. This will be done without trouble or violence, and it will be optional for all owners of property either to adopt the new system or to retain the old one. He detailed the steps which are being taken for the spread of public instruction both by the Government authorities and the eminent prelate who governs the Church in North Africa, Cardinal Lavigérie, and the means adopted by the Government for the archæological exploration of the Regency, still almost a virgin field. And lastly he gave a short summary of the daring project of Commandant Roudaire for the creation of an inland sea by the submersion of the Sahara.

FRIDAY, SEPTEMBER 11.

The PRESIDENT delivered the following Address:—

MY predecessors in this chair have claimed for geography a range of science which may be said to be practically unlimited; for it comprehends the history of the earth itself, and of all the life to be met with on the surface of the earth, from the first beginnings of things, and through their subsequent development onwards to their present conditional status; it is associated in a greater or less degree with every other department of knowledge, and is a remarkable exemplification of the mutual interdependence and correlation of the physical sciences, for while all other branches of science are incomplete without some knowledge of geography, it is incomplete without some knowledge of each and all of them.

Such claims on behalf of geography would, not many years ago, have been considered extravagant and exaggerated; a popular encyclopædia which is still of some note defines geography to be simply the science which describes the surface of the earth, and somewhat querulously complains that geographical treatises contain matter not unfrequently taken from statistics, natural philosophy, and history which it declares to be irrelevant and not properly admissible into such treatises. And in a popular sense geography is still commonly suggestive only of such a knowledge of locality as may be acquired from maps and charts, with their graphical delineations of whatever exists on the surface of the earth, and of the various natural or artificial boundary lines of the peoples and states between whom the surface is divided. But the British Association and the Royal Geographical Society have successfully maintained that scientific geography is not restricted in its scope to a mere knowledge of locality—though that in itself is a very important factor in whatever appertains to the intercourse and mutual relations of mankind—but embraces all that relates to the structure and existing configuration of the earth, and takes cognizance of the varied conditions of all the life, both animal and vegetable, which is nurtured and supported by the earth; it studies the side lights which the general configuration of surface throws on the character of each locality as a home and support of life, and it examines with special interest the influence which that character has exerted on the social and political conditions of different races and peoples.

And geography does not merely devote its attention to the existing order of things as now displayed to our gaze; in alliance with geology it studies the history

of a distant past, when the features of the earth's surface were not precisely as now, and lands which we see high above our horizon lay deep beneath the ocean, and life existed in other forms, whose mute records we possess in the fossils—the *likha-kân*, or written stones as they are significantly called by the people of Afghanistan—which, after long lying entombed among the rocks, are presented to modern sight as revelations of life's early dawn; it investigates what Baron Richtofen describes as the reciprocal causal relations of the three kingdoms—land, water, and atmosphere; it seeks to determine the processes by which in some parts of the globe continents were built up with their varied sculpture of mountain and valley, of highly elevated plateau and low lying plain, of lakes and inland seas, and great river systems,—while in other parts land was depressed below the sea level, or broken up into the islands which are now dotting the surface of the ocean; and it endeavours to trace a process of continuous evolution of life from the primary and simplest types which perished in the early ages of the earth's history, to the latest and most highly developed types which are now flourishing around us. Going back still further it searches for evidence of the first beginnings of the material universe; it looks beyond the orbit of the most distant planet of the solar system, and scrutinises the boundless regions of stellar space to find, in the widely scattered particles of the nebulæ, the beginnings of new solar systems and new worlds such as ours; there it may be said to behold as in a mirror the formation of our own planet as a fluid igneous mass thrown off with great velocity from its sun, and rapidly revolving, and then becoming spheroidal, and slowly cooling and solidifying, and finally acquiring the crust which was to become an abode for life, the stage whereon man was to play out the drama of his planetary existence, and be held all the while fast imprisoned and out of touch with the surrounding universe.

More than this we would seek to know, but in vain; in passing from the early dawn of matter to that of life, science finds its career of wonderful achievement in the one direction exchanged for failure and disappointment in the other; it cannot discover the origin of life in any of its existing material forms, nor trace to its birthplace the spiritual life which exerts such an influence on what is material; it cannot ascertain whether man had a prior existence as different from his present existence as the first beginnings of his planet home differed from its present condition; it cannot gauge the truth of the poet's prescient conception that

> 'Our birth is but a sleep and a forgetting;
> The soul that rises with us, our life's star,
> Hath had elsewhere its setting
> And cometh from afar.'

It whispers faint suggestions regarding the possible future of the planet; but when questioned as to what is to follow the coming soul's setting of man, the planet's chief glory and dignity, it has nothing to reply, but is hopelessly dumb and inarticulate.

Scientific geography embraces a wide range of subjects, wider than can be claimed for any other department of science. Thus the President of this Section has a vast field from which to gather subjects for his opening address. I shall, however, restrict my address to the subject with which I am most familiar, and give you some account of the Survey of India, and more particularly of the labours of the trigonometrical or geodetic branch of that survey, in which the best years of my life have been passed.

I must begin by pointing out that the survey operations in India have been very varied in nature, and constitute a blending together of many diverse ingredients. Their origin was purely European, nothing in the shape of a general survey having been executed under the previous Asiatic Governments; lands had been measured in certain localities, but merely with a view to acquiring some idea of the relative areas of properties, in assessing on individuals the share of the revenue levied on a community; but other factors than area—such as richness or poverty of soil, and proximity or absence of water—influenced the assessment, and often in a greater degree, so that very exact measurements of area were not wanted for revenue purposes, and no other reason then suggested itself why lands should be accurately

measured. The value of accurate maps of individual properties, with every boundary clearly and exactly laid down, was not thought of in India in those days, and indeed has only of late years began to be recognised by even the British Government. The idea of a general geographical survey never suggested itself to the Asiatic mind. Thus when Englishmen came to settle in India, one of their first acts was to make surveys of the tracts of country over which their influence was extending; and as that influence increased, so the survey became developed from a rude and rapid primary delineation of the broad facts of general geography, to an elaborately executed and artistic delineation of the topography of the country, and in some provinces to the mapping of every field and individual property. Thus there have been three orders or classes of survey, and these may be respectively designated geographical, topographical, and cadastral; all three have frequently been carried on *pari passu,* but in different regions, demanding more or less elaborate survey according as they happened to be more or less under British influence. There is also the Great Trigonometrical or Geodetic Survey, by which the graphical surveys are controlled, collated, and co-ordinated, as I will presently explain.

Survey operations in India began along the coast-lines before the commencement of the seventeenth century, the sailors preceding the land surveyors by upwards of a century. The Directors of the East India Company, recognising the importance of correct geographical information for their mercantile enterprises, appointed Richard Hakluyt, Archdeacon of Westminster, their historiographer and custodian of the journals of East Indian voyages, in the year 1601, within a few weeks of the establishment of the company by Royal Charter. Hakluyt gave lectures to the students at Oxford, and is said by Fuller to have been the first to exhibit the old and imperfect maps and the new and revised maps for comparison in the common schools, 'to the singular pleasure and great contentment of his auditory.' The first general map of India was published in 1752 by the celebrated French geographer D'Anville, and was a meritorious compilation from the existing charts of coast-lines and itineraries of travellers. But the Father of Indian Geography, as he has been called, was Major Rennell, who landed in India as a midshipman of the Royal Navy in 1760, distinguished himself in the blockade of Pondicherry, was employed for a time in making surveys of the coast between the Paumben Passage and Calcutta, was appointed Surveyor of the East India Company's dominions in Bengal in 1764, was one of the first officers to receive a commission in the Bengal Engineers on its formation, and in 1767 was raised to the position of Surveyor-General. Bengal was not in those days the tranquil country we have known it for so many years, but was infested by numerous bands of brigands who professed to be religious devotees, and with whom Rennell came into collision in the course of one of his surveying expeditions, and was desperately wounded; he had to be taken 300 miles in an open boat for medical assistance, the natives meanwhile applying onions to his wounds as a cataplasm. His labours in the survey of Bengal lasted over a period of nineteen years, and embraced an area of about 300,000 square miles, extending from the eastern boundaries of Lower Bengal to Agra, and from the Himalayas to the borders of Bandelkand and Chota Nagpur. Ill-health then compelled him to retire from the service on a small pension and return to England; but not caring, as he said, to eat the bread of idleness, he immediately set himself to the utilisation of the large mass of geographical materials laid up and perishing in what was then called the India House; he published numerous charts and maps, and eventually brought out his great work on Indian Geography, the 'Memoir of a map of Hindostan,' which went through several editions; this was followed by his Geographical System of Herodotus, and various other works of interest and importance. His labours in England extended over a period of thirty-five years, and their great merits have been universally acknowledged.

Rennell's system of field-work in Bengal was a survey of routes checked and combined by astronomical determinations of the latitude and the longitude, and a similar system was adopted in all other parts of India until the commencement of the present century. But in course of time the astronomical basis was found to be inadequate to the requirements of a general survey of all India, as the errors in the astrono-

mical observations were liable materially to exceed those of the survey, if executed with fairly good instruments and moderate care. Now this was no new discovery, for already early in the eighteenth century the French Jesuits who were making a survey of China—with the hope of securing the protection of the Emperor, which they considered necessary to favour the progress of Christianity—had deliberately abandoned the astronomical method and employed triangulation instead. Writing in the name of the missionaries who were associated with him in the survey, Père Regis enters fully into the relative advantages of the two methods, and gives the trigonometrical the preference, as best suited to enable the work to be executed in a manner worthy the trust reposed in them by a wise prince, who judged it of the greatest importance to his State. 'Thus,' he says, 'we flatter ourselves we have followed the surest course, and even the only one practicable in prosecuting the greatest geographical work that was ever performed according to the rules of art.'

What was true in those days is true still; points whose relative positions have been fixed by any triangulation of moderate accuracy present a more satisfactory and reliable basis for topographical survey than points fixed astronomically. Though the lunar theory has been greatly developed since those days by the labours of eminent mathematicians, and the accuracy of the lunar tables and star catalogues is much increased, absolute longitudes are still not susceptible of ready determination with great exactitude; moreover, all astronomical observations, whether of latitude or longitude, are liable to other than intrinsic errors, which arise from deflection of the plumb-line under the influence of local attractions, and which of themselves materially exceed the errors that would be generated in any fairly executed triangulation of a not excessive length, say not exceeding 500 miles.

Thus at the close of the last century Major Lambton, of the 33rd Regiment, drew up a project for a general triangulation of Southern India. It was strongly supported by his commanding officer—Colonel Wellesley, afterwards the Duke of Wellington—and was readily sanctioned by the Madras Government; for a large accession of territory in the centre of the peninsula had been recently acquired, as the result of the Mysore campaign, by which free communication had been opened between the east and west coasts, of Coromandel and Malabar; and the proposed triangulation would not merely furnish a basis for new surveys, but connect together various isolated surveys which had already been completed or were then in progress. The Great Trigonometrical Survey of India owes its origin as such, and its simultaneous inception as a geodetic survey, to Major Lambton, who pointed out that the trigonometrical stations must needs have their latitudes and longitudes determined for future reference just as the discarded astronomical stations, not however by direct observation, but by processes of calculation requiring a knowledge of the earth's figure and dimensions. But at that time the elements of the earth's figure were not known with much exactitude, for all the best geodetic arcs had been measured in high latitudes, the single short and somewhat questionable arc of Peru being the only one situated in the vicinity of the equator. Thus additional arcs in low latitudes, as those of India, were greatly needed and might be furnished by Lambton. He took care to set this forth very distinctly in the programme which he drew up for the consideration of the Madras Government, remarking that there was thus something still left as a desideratum for the science of geodesy, which his operations might supply, and that he would rejoice indeed should it come within his province 'to make observations tending to elucidate so sublime a subject.'

Lambton commenced operations by measuring a base line and a small meridional arc near Madras, and then, casting a set of triangles over the southern peninsula, he converted the triangles on the central meridian into a portion of what is now known as the Great Arc of India, measuring its angles with extreme care, and checking the triangulation by base lines measured at distances of 2 to 3 degrees apart in latitude. His principal instruments were a steel measuring chain, a great theodolite, and a zenith sector, each of which had a history of its own before coming into his hands. The chain and zenith sector were sent from England with

Lord Macartney's Embassy to the Emperor of China, as gifts for presentation to that potentate, who unfortunately did not appreciate their value and declined to accept them; they were then made over to Dr. Dinwiddie, the astronomer to the embassy, who took them to India for sale. The theodolite was constructed in England for Lambton, on the model of one in use on the Ordnance Survey; on its passage to India it was captured by the French frigate, the *Piemontaise*, and landed at Mauritius, but eventually it was forwarded to its destination by the chivalrous French Governor, De Caen, with a complimentary letter to the Governor of Madras.

Lambton was assisted for a short time by Captain Kater, whose name is now best known in connection with pendulum experiments and the employment of the seconds' pendulum as a standard of length; but for many years afterwards he had no officer to assist him. At first he met with much opposition from advocates of the discarded astronomical method, who insisted on its being sufficiently accurate and more economical than the trigonometrical. But he was warmly supported by Maskelyne, the Astronomer-Royal in England; and he soon had an opportunity of demonstrating the astronomical method to be fallacious, for its determination of the breadth of the peninsula in the latitude of Madras was proved by the triangulation to be forty miles in error. Still, for several years he never received a word of sympathy, encouragement, or advice either from the Government or from the Royal Society. A foreign nation was the first to recognise the importance of his services to science, the French Institute electing him a corresponding member in 1817. After this, honours and applause quickly followed from his own countrymen. In 1818 the then Governor-General of India—the Marquis of Hastings—decided that the survey should be withdrawn from the supervision of a local government and placed under the Supreme Government, with a view to its extension over all India, remarking at the same time that he was 'not unaware that with minds of a certain order he might lay himself open to the idle imputation of vainly seeking to partake the gale of public favour and applause which the labours of Colonel Lambton had recently attracted;' but as the survey had reached the northern limits of the Madras Presidency, its transfer to the Supreme Government, if it was to be further extended, had become a necessity. He directed the transfer to be made, and the survey to be called in future the Great Trigonometrical Survey of India. Noticing that the intense mental and bodily labour of conducting it was being performed by Lambton alone, that his rank and advancing age demanded some relief from such severe fatigue, and farther, that it was not right that an undertaking of such importance should hang on the life of a single individual, the Governor-General appointed two officers to assist him—Captain Everest, as chief assistant in the geodetic operations; and Dr. Voysey, as surgeon and geologist. Five years afterwards Lambton died, at the age of 70. The happy possessor of an unusually robust and energetic constitution and a genial temperament, he seems to have scarcely known a day's illness, though he never spared himself nor shrank from subjecting himself to privations and exposure which even Everest thought reckless and unjustifiable. These he accepted as a matter of course, saying little about them, and devoting his life calmly and unostentatiously to the interests of science and the service of his country.

Everest's career in the survey commenced disastrously. He was deputed by Lambton to carry a triangulation from Hydrabad, in the Nizam's territory, eastwards to the coast, crossing the forest-clad and fever-haunted basin of the Godavery river, a region which he described as 'a dreadful wilderness, than which no part of the earth was more dreary, desolate, and fatal.' Indignant at being taken there, his escort, a detachment of the Nizam's troops, mutinied, and soon afterwards he and his assistants, and almost all the men of his native establishment, were stricken down by a malignant fever; many died on the spot, and the survivors had to be carried into Hydrabad, whence litters and vehicles of all descriptions, and the whole of the public elephants, were despatched to their succour. To recover his health Everest was compelled to leave India for a while and proceed to the Cape of Good Hope, where he remained for three years. He availed himself of the opportunity to inspect Lacaille's meridional arc, which, when compared with the

arcs north of the equator, indicated that the opposite hemispheres of the globe were seemingly of different ellipticities. He succeeded in tracing this anomaly to an error in the astronomical amplitude of the arc, which had been caused by deflection of the plumb-line at the ends of the arc, under the influence of the attraction of neighbouring mountains. Thus he became aware of the necessity of placing the astronomical stations of the Indian arcs at points where the plumb-line would not be liable to material deflection by the attraction of neighbouring mountain ranges. Shortly after his return to India Lambton died, and Everest succeeded him, and immediately concentrated his energies on the extension of the Great Arc northwards. He soon came to the conclusion that his instrumental equipment, though good for the time when it was procured, and amply sufficient for ordinary geographical purposes, was inadequate for the requirements of geodesy, and generally inferior to the equipments of the geodetic surveys then in progress in Europe. He therefore proceeded to Europe to study the procedure of the English and French surveys, and also to obtain a supply of new instruments of the latest and most improved forms. The Court of Directors of the Honourable East India Company accorded a most liberal assent to all his proposals, and gave him *carte blanche* to provide himself with whatever he considered desirable to satisfy all the requirements of science.

Everest returned to India with his new instrumental equipment in 1830, a year that marks the transition of the character of the operations from an order of accuracy which was sufficient as a basis for the graphical delineation of a comparatively small portion of the earth's surface, to the higher precision and refinement which modern geodesists have deemed essentially necessary for the determination of the figure and dimensions of the earth as a whole. He immediately introduced an important modification of the general design of the principal triangulation, which up to that time had been thrown as a network over the country on either side of the Great Arc, as in the English survey and many others; but he abandoned this method, and, adopting that of the French survey instead, he devised a system of meridional chains, to be carried at intervals of about 1° apart, and tied together by longitudinal chains at intervals of about 5°, the whole forming, from its resemblance to the homely culinary utensil with which we are all familiar, what has been called the gridiron system in contradistinction to the network. The entire triangulation was to rest on base-lines to be measured with the new Colby apparatus of compensation bars and microscopes which had been constructed to supersede the measuring chain the Emperor of China had rejected; the base-lines were to be placed at the intersections of the longitudinal chains of triangles with the central meridional or axial chain, and also at the further angles of the gridirons on each side. Latitudes were to be measured at certain of the stations of the central chain, with new astronomical circles in place of the old zenith sector, to give the required meridional arcs of amplitude. Two radical improvements on all previous procedure were introduced in the measurement of the principal angles, one affecting the observations, the other the objects observed. The great theodolites were manipulated in such a manner as not merely to reduce the effects of accidental errors by numerous repetitions in the usual way, but absolutely to eliminate all periodic errors of graduation by systematic changes of the position of the azimuthal circle relatively to the telescope, in the course of the complete series of measures of every angle. The objects formerly observed had been cairns of stones or other opaque signals; for these Everest substituted luminous signals, lamps by night, and, by day, heliotropes which were manipulated to reflect the sun's rays through diaphragms of small aperture, in pencils appearing like bright stars and capable of penetrating a dense atmosphere through which distant opaque objects could not be seen.

Everest's programme of procedure furnished the guiding principles on which the operations were carried out during the period of half a century which intervened between their commencement under his superintendence and the completion of the principal triangulation under myself. The external chains have necessarily been taken along the winding course of the frontier and coast lines instead of the direct and more symmetrical lines of the meridians and the parallels of latitude. The

number of the internal meridional chains has latterly been diminished by widening the spaces between them, and in two instances a principal chain has been dispensed with because, before it could be taken in hand, a good secondary triangulation had been carried over the area for which it was intended to provide. But these are departures from the letter rather than the spirit of Everest's programme, which has been faithfully followed throughout, first by his immediate successor, Sir Andrew Waugh, and afterwards by myself, thus affording an instance of the impress of a single mind on the work of half a century which is probably unique in the annals of India; for there, as is well known, changes of personal administration are frequent, and are not uncommonly followed by changes of procedure.

The physical features of a country necessarily exercise a considerable influence on the operations of any survey that may be carried over it, and more particularly on those of a geodetic survey, of which no portion is allowed to fall below a certain standard of precision. Every variety of feature, of scenery, and of climate that is to be met with anywhere on the earth's surface between the equator and the arctic regions has its analogue between the highlands of Central Asia and the ocean, which define the limits of the area covered by the Indian survey. Thus in some parts the operations were accomplished with ease, celerity, and enjoyment, while in others they were very difficult and slow of progress, always entailing great exposure, and at times very deadly. In an open country, dotted with hills and commanding eminences, they advanced as on velvet; in close country, forest-clad or covered with other obstacles to distant vision, they were greatly retarded, for there it became necessary either to raise the stations to a sufficient height to overlook all surrounding obstacles, or to render them mutually visible by clearing the lines between them; and both these processes are more or less tedious and costly. There are many tracts of forest and jungle which greatly impeded the operations, not merely because of the physical difficulties they presented, but because they teemed with malaria, and were very deadly during the greater portion of the year, and more particularly immediately after the rainy seasons, when the atmosphere is usually clearest and most favourable for distant observations. At first tracts of forest, covering extensive plains, were considered impracticable; thus Lambton carried his network over the open country, and stopped it whenever it reached a great plain covered with forest and devoid of hills; but Everest's system would not permit of any break of continuity, nor the abandonment of any chain which was required to complete a gridiron; it has been carried out in all its integrity, often with much sacrifice of life, but never with any shrinking on the part of the survey officers from carrying out what it had become a point of honour with them to accomplish, and the accomplishment of which the Government had come to regard as a matter of course. We have already seen how the progress of Everest's first chain of triangles was suddenly arrested, because he and all his people were struck down by malaria in the pestilential regions of the Godavery basin. That chain remained untouched for fifty years; it was then resumed and completed, but with the loss of the executive officer, Mr. George Shelverton, who succumbed when he had not yet reached, but was within sight of, the east coast line, the goal towards which his labours were directed. Many regions, as the basin of the Mahanaddi, the valley of Assam, the hill ranges of Tipperah, Chittagong, Arracan, and Burma, and those to the east of Moulmein and Tennasserim, which form the boundary between the British and the Siamese territories, are covered with dense forest, up to the summits of the peaks which had to be adopted as the sites of the survey stations. As a rule the peaks were far from the nearest habitation, and they could not be reached until pathways to them had been cut through forests tangled with a dense undergrowth of tropical jungle; not unfrequently large areas had to be cleared on the summits to open out the view of the surrounding country. Here the physical difficulties to be overcome were very considerable, and they were increased by the necessity that arose, in almost every instance, of importing labourers from a great distance to perform the necessary clearances. But the broad belt of forest tract known as the Terai, which is situated in the plains at the foot of the Nepalese Himalayas, was the most formidable region of all, because the climate was very deadly for a great portion of the year, and more particularly during the

season when the atmosphere was most favourable for the observations, though the physical difficulties were not so great as in the hill tracts just mentioned, and labour was more easily procurable. Lying on the British frontier, at the northern extremities of no less than ten of the meridional chains of triangles, it had necessarily to be operated in to some extent, and Everest wished to carry the several chains across it, on to the outer Himalayan range, and then to connect them together by a longitudinal chain running along the range from east to west, completing the gridiron in this quarter. But the range was a portion of the Nepalese territories, and all Europeans—excepting those attached to the British embassy at Khatmandu—were debarred from entering any part of Nepal, by treaty with the British Government. Everest hoped that the rulers of Nepal might make an exception in his favour for the prosecution of a scientific survey; and when he found they would not, he urged the Government to compel them to give his surveyors access, at least, to their outlying hills; but he urged in vain, for the Government would not run the risk of embarking in a war with Nepal for purely scientific interests. Thus the connecting chain of triangles—now known as the N.E. Longitudinal Series—had to be carried through the whole length of the Terai, a distance of about 500 miles, which involved the construction of over 100 towers—raised to a height of about 30 feet to overlook the earth's curvature—and the clearance of about 2,000 miles of line through forest and jungle to render the towers mutually visible. It required no small courage on Everest's part to plunge his surveyors into this region; he endeavoured to minimise the risks as much as possible by taking up the longitudinal chain in sections, bit by bit, on the completion of the successive meridional chains, and thus apportioning it between several survey parties, each operating in the Terai for a short time, instead of assigning it to a single party to execute continuously from end to end, as all the other chains of triangles. But notwithstanding these precautions, the peril was great, and the mortality among both officers and men was very considerable; greater than in many a famous battle, says Mr. Clements Markham, in an eloquent passage in his Memoir of the Indian Surveys, in which he claims for the surveyors who were employed on these operations—with no hope of reward other than the favourable notice of their immediate chief and colleagues—merit for more perilous and honourable achievement than much of the military service which is plentifully rewarded by the praises of men and prizes of all kinds.

Everest retired in 1843, and was succeeded by Waugh, who applied himself energetically to the completion of the several chains of triangles exterior to the Great Arc, for which he obtained a substantial addition to the existing equipment of great theodolites. It was under him that the formidable longitudinal series through the Terai, which had been begun by Everest, was chiefly carried out. He personally initiated the determination of the positions and heights of the principal snow peaks of the Himalayan ranges; and he did much for the advancement of the general topography of India, which had somewhat languished under his predecessor, who had devoted himself chiefly to the geodetic operations. He retired in 1861, and I succeeded to the charge of the Great Trigonometrical Survey. The last chain of the principal triangulation was completed in 1882, shortly before my own retirement.

Of the general character of the operations, it may be asserted without hesitation that a degree of accuracy and precision has been attained which has been reached by few and surpassed by none of the great national surveys carried out in other parts of the world, and which leaves nothing to be desired even for the requirements of geodesy; a very considerable majority of the principal angles have been measured with the great 24-inch and 36-inch theodolite, and their theoretical probable error averages about a quarter of a second; of the linear measurements the probable error, so far as calculable, may be taken as not exceeding the two-millionth part of any measured length. And as regards the extent of the triangulation, if we ignore the primary network in Southern India, and all secondary triangulation, however valuable for geographical purposes, we still have a number of principal chains—meridional, longitudinal, and oblique—of which the aggregate length is 17,300 miles, which contain 9,230 first-class angles all observed, and rest on eleven

base-lines measured with the Colby apparatus of compensation bars and microscopes. This prodigious amount of field-work furnishes an enormous mass of interdependent angular and linear measures; and each of these is fallible in some degree, for, great as was the accuracy and care with which they had severally been executed, perfect accuracy of measurement is as yet beyond human achievement; thus every circuit of triangles, every chain closing on a base-line, and even every single triangle, presented discrepancies the magnitude of which was greater or less according as derived from a combination of many, or only of a few, of the fallible facts of observation. Thus, when the field operations were approaching their termination, the question arose as to how these facts were to be harmonised and rendered consistent throughout, which was a very serious matter considering their great number. The strict application of mathematical theory to a problem of this nature requires the adjustment to be effected by the application of a correction to every fact of observation, not arbitrarily, but in such a manner as to give it its proper weight, neither more nor less, in the final investigation, and in this the whole of the facts must be treated simultaneously. That would have involved the simultaneous solution of upwards of 4,000 equations between 9,230 unknown quantities, by what is called the method of minimum squares, and I need scarcely say that it is practically impossible to solve such a number of equations between so many unknown quantities by any method at all. Thus a compromise had to be made between the theoretically desirable and the practically possible. It would be out of place here to attempt to describe the method of treatment which was eventually adopted, after much thought and deliberation; I will merely say that the bulk of the triangulation was divided into five sections, each of which was treated in succession with as close approximation to the mathematically rigorous method as was practically possible; but even then the mass of simultaneous interdependent calculation to be performed in each instance was enormous, I believe greatly exceeding anything of the kind as yet attempted in any other survey. But the happy result of all this labour was that the final corrections of the angles were for the most part very minute, less than the theoretical probable errors of the angles, and thus fairly applicable without taking any liberties with the facts of observation. If the attribute of beauty may ever be bestowed on such things as small numerical quantities, it may surely be accorded to these notable results of very laborious calculations, which, while in themselves so small, were so admirably effective in introducing harmony and precision throughout the entire triangulation.

If now we turn once more to what Lambton calls 'the sublime science of geodesy,' which was held in such high regard by both him and Everest, we shall find that the great meridional arc between Cape Comorin and the Himalayas, on which they laboured with so much energy and devotion, is not the only contribution to that science to which the Indian triangulation is subservient, but every chain of triangles —meridional, longitudinal, or oblique—may be made to throw light either on geodesy, the science of the figure of the earth, or on geognosy, the science of the earth's interior structure, when combined with corresponding astronomical arcs of amplitude. Thus each of the several meridional chains of triangles may be utilised in this way, as their prototype has been, by having latitude observations taken at certain of their stations to give meridional arcs; and the several longitudinal chains of triangles may also be utilised—in combination with the main lines of telegraph—by electro-telegraphic determinations of differential longitudes to give arcs of parallel. When the stations of the triangulation which are resorted to for the astronomical observations are situated in localities where the normal to the surface coincides fairly with the corresponding normal to the earth's figure, the result is valuable as a contribution to geodesy; when the normal to the surface is sensibly deflected by local attraction, the result gives a measure of the deflection which is valuable as a contribution to geognosy.

Having regard to these circumstances, I moved the Government to supply the Trigonometrical Survey with the necessary instruments for the measurement of the supplemental astronomical arcs; and as officers became available on the gradual completion of the successive chains of triangles, I employed some of them in the required determinations of latitude and differential longitude. It so happened that

about the same time geodesists in Europe began to recognise the advantages to science to be acquired by connecting the triangulations of the different nationalities together, and supplementing them with arcs of amplitude. The 'International Geodetic Association for the Measurement of Degrees in Europe' was formed in consequence, and it has been, and is still, actively employed in carrying out this object; in India, however, the triangulation was complete and connected throughout, so that only the astronomical amplitudes were wanting. They are still in progress, but already meridional chains, aggregating 1,840 miles in length, and lying to the west of the Great Arc, have been converted into meridional arcs; and the three longitudinal chains, from Madras to Mangalore, from Bombay to Vizagapatam, and from Kurrachee *viâ* Calcutta to Chittagong, of which the aggregate length is 2,600 miles, have been converted into arcs of parallel. In the former the operations follow the meridional course of the chains of triangles; in the latter they follow the principal lines of the electric telegraph, which sometimes diverge greatly from the direction of the longitudinal chains of triangles, the two only intersecting at occasional points; the astronomical stations are therefore placed at the trigonometrical points which may happen to be nearest the telegraph lines, whether on the meridional or on the longitudinal chains, and their positions are invariably so selected as to form self-verificatory circuits which are usually of a triangular form, presenting three differential arcs of longitude; each of these arcs is measured independently as regards the astronomical work—though for the third arc there is usually no independent telegraph line, but only a coupling of the lines for the first and second arcs—and this has been proved to give such an excellent check on the accuracy of the operations, that it is not too much to say that no telegraphic longitude operations are entirely reliable which have not been verified in some such manner.

Through the courtesy of Colonel Stotherd, Director-General of the Ordnance Survey, I am enabled to exhibit two charts, one of the triangulation of India, the other of that of Europe, which have recently been enlarged to the same scale in the Ordnance Survey Office at Southampton for purposes of comparison. The first is taken from the official chart of the Indian survey, and shows the great meridional and longitudinal chains and Lambton's network of principal triangles, the positions of the base-lines measured with the Colby apparatus, the latitude and the differential longitude stations, the triangular circuits of the longitudinal arcs, the stations of the pendulum and the tidal operations which will be noticed presently, and the secondary triangulations to fix the peaks of the Himalayan and Sulimani ranges, and the positions of Bangkok in Siam and Kandahar in Afghanistan, the extreme eastern and western points yet reached. The chart of the European triangulation has been enlarged from one published by the International Geodetic Association of Europe; in it special prominence is given to the Russian meridional arc, which extends from the Danube to the Arctic Ocean, and is 25° 20′ in length, and to the combined English and French meridional arc, 22° 10′ in length, which extends from the Balearic Island of Formentera in the Mediterranean, to Saxavord in the Shetland Islands. The aggregate length of the meridional arcs already completed in India is about equal to that of the English, French and Russian arcs combined; but the longest in India is about $1\frac{1}{2}$° shorter than the Russian. As regards longitudinal arcs, I believe the two which were first measured in India, and were employed shortly afterwards by Colonel Clarke in his last investigation of the figure of the Earth, are the only ones which have as yet been deemed sufficiently accurate to be made use of in such investigations, though arcs of much greater length have been measured in Europe. It would be interesting, if time permitted, to set forth the salient points of divergence between the systems of the Indian and the European surveys; I will only mention that in the southern part of the Russian arc, for a space of about 8° from the Duna to the Dneister, a vast plain, covered with immense and almost impenetrable forests, presented great obstacles to the prosecution of the work; the difficulty was overcome by the erection of a large number of lofty stations of observation, wooden scaffoldings which were 120 and even as much as 146 feet high, to overlook the forests. In Indian forests, as the Terai on the borders between British and Nepalese territories, the stations were

rarely raised to a greater height than 30 feet, or just sufficient to overtop the curvature, and all trees and other obstacles were cleared away on the lines between them; this was found the most expeditious and economical process. The stations were very substantial, with a central masonry pillar, for the support of a great theodolite, which was isolated from the surrounding platform for the support of the observer. The lofty Russian scaffoldings only sufficed for small theodolites, and they were so liable to shake and vibration that the theodolites had to be fitted with two telescopes to be pointed simultaneously by two observers at the pair of stations, the angle between which was being measured.

All the modern geodetic data of the Indian survey that were available up to the year 1880 were utilised by Colonel A. R. Clarke, C.B., of the Ordnance Survey, in the last of the very valuable investigations of the Figure of the Earth which he has undertaken from time to time. It will be obvious that new data tend to modify in some degree the conclusions derived from previous data, for the figure of so large a globe as our earth is not to be exactly determined from measurements carried over a few narrow belts of its superficies. Thus thirty years ago it was inferred that the equator was sensibly elliptic—and not circular, as had been generally assumed—with its major axis in longitude 15° 34′ east of Greenwich; but later investigations indicate a far smaller ellipticity, and place the major axis in west longitude 8° 15′. More significant evidence of the influence of new facts of observation in modifying previous conclusions is furnished by the French national standard of length, the mètre, which was fixed at the ten-millionth part of the length of the earth's meridional quadrant, as deduced from the best geodetic data available up to the end of the last century; but it is now found to be nearly $\frac{1}{5000}$th part less than the magnitude which it is supposed to represent, the difference being about a hundred times greater than what would now be considered an allowable error in an important national standard of measure.

The Indian survey has also made valuable contributions to geodesy and geognosy in an elaborate series of pendulum observations for determining variations of gravity, which throws light both on the grand variation from the poles to the equator that governs the ellipticity, and on the local and irregular variations depending on the constitution of the interior of the earth's crust. They were commenced in 1865 by Captain J. P. Basevi, on the recommendation of General Sabine and the Council of the Royal Society, with two pendulums, one of which the General had swung in his notable operations which extend from a little below the equator to within 10° of the pole. Captain Basevi had nearly completed the operations in India, and had taken swings at a number of the stations of the Great Arc and at various other points near mountain ranges and coast lines, when he died of exposure in 1871 at a station on the high table lands of the Himalayas, while investigating the force of gravity under mountain ranges. Major Heaviside swung the pendulums at the remaining Indian stations, then at Aden and Ismailia on the way back to England, and finally at the base station, the Kew Observatory. Afterwards they and a third pendulum were swung at Kew and Greenwich by Lieutenant-Colonel Herschel, who took all three to America, swung them at Washington, and then handed them over to officers of the United States Coast Survey, by whom they have been swung at San Francisco, Auckland, Sydney, Singapore, and in Japan.

The pendulum operations in India have been successful in removing from the geodetic operations the reproach which had latterly been cast on them, that their value has become much diminished since the discovery that the attraction of the Himalayan mountains is so much greater than had previously been suspected, that it may have materially deflected the plumb-line at a large number of the astronomical stations of the Great Arc, and injuriously influenced the observations. Everest considered the effects of the Himalayan attraction to be immaterial at any distance exceeding sixty miles from the foot of the mountains; but in his days the full extent and elevation of the mountain masses was unknown, and their magnitude was greatly underestimated. Afterwards, when the magnitude became better known, Archdeacon Pratt of Calcutta, a mathematician of great eminence, calculated that they would materially attract the plumb-line at points many hundred miles

distant; he also found that everywhere between the Himalayas and the ocean, the excess of density of the land of the continent as compared with the water of the ocean would combine with the Himalayan attraction and increase the deflection of the plumb-line northwards, towards the great mountain ranges, and that under the joint influence of the Himalayas and the ocean the level of the sea at Kurrachee would be raised 560 feet above the level at Cape Comorin.

But as a matter of fact the Indian arc gave a value of the earth's ellipticity which agreed sufficiently closely with the values derived from the arcs measured in all other quarters of the globe, to show that it could not have been largely distorted by deflections of the plumb-line; thus it appeared that whereas Everest might have slightly underestimated the Himalayan attraction, Pratt must have greatly over-estimated it. His calculations were however based on reliable data, and were indubitably correct. For some time the contradiction remained unexplained, but eventually Sir George Airy put forward the hypothesis that the influence of the Himalayan masses must be counteracted by some compensatory disposition of the matter of the earth's crust immediately below them, and in which they are rooted; he suggested that the bases of the mountains had sunk to some depth into a fluid lava which he conceived to exist below the earth's crust, and that the sinking had caused a displacement of dense matter by lighter matter below, which would tend to compensate for the excess of matter above. Now Pratt's calculations had reference only to the visible mountain and oceanic masses, and their attractive influences—the former positive, the latter negative—in a horizontal direction; he had no data for investigating the density of the crust of the earth below either the mountains on the one hand, or the bed of the ocean on the other. The pendulum observations furnished the first direct measures of the vertical force of gravity in different localities which were obtained, and these measures revealed two broad facts regarding the disposition of the invisible matter below; first, that the force of gravity diminishes as the mountains are approached, and is very much less on the summit of the highly elevated Himalayan table lands than can be accounted for otherwise than by a deficiency of matter below; secondly, that it increases as the ocean is approached, and is greater on islands than can be accounted for otherwise than by an excess of matter below. Assuming gravity to be normal on the coast lines, the mean observed increase at the island stations was such as to cause a seconds' pendulum to gain three seconds daily, and the mean observed decrease in the interior of the Continent would have caused the pendulum to lose $2\frac{1}{2}$ seconds daily at stations averaging 1,200 feet above the sea level, 5 seconds at 3,800 feet, and about 22 seconds at 15,400 feet—the highest elevation reached—in excess of the normal loss of rate due to height above the sea.

Pratt was strongly opposed to the hypothesis of a substratum, or magma, of fluid igneous rock beneath the mountains; he assumed the earth to be solid throughout, and regarded the mountains as an expansion of the invisible matter below, which thus becomes attenuated and lighter than it is under regions of less elevation, and more particularly in the depressions and contractions below the bed of the ocean. And certainly we seem to have more reason to conclude that the mountains emanate from the subjacent matter of the earth's crust than that they are as wholly independent of it as if they were formed of stuff shot from passing meteors and asteroids; any severance of continuity and association between the visible above and the invisible below appears, on the face of it, to be decidedly improbable.

The hypothesis of sub-continental attenuation and sub-oceanic condensation of matter is supported by the two arcs of longitude on the parallels of Madras and Bombay; for at the extreme points of these arcs, which are situated on the opposite coast lines, the horizontal attraction has been found to be not landwards, as might have been anticipated, but seawards, showing that the deficient density of the sea as compared with the land is more than compensated by the greater density of the matter under the ocean than of that under the land.

While on the subject of the constitution of the earth's crust, I may draw attention to the circumstance that the tidal observations which have been carried on at a number of points on the coasts of India, as a part of the operations of the

Survey, tend to show that the earth is solid to its core, and that the geological hypothesis of a fluid interior is untenable. They have been analysed by Professor G. H. Darwin, with a view to the determination of a numerical estimate of the rigidity of the earth, and he has ascertained that whilst there is some evidence of a tidal yielding of the earth's mass, that yielding is certainly small, and the effective rigidity is very considerable, not so great as that of steel as was at first surmised, but sufficient to afford an important confirmation of the justice of Sir William Thomson's conclusion as to the great rigidity.

The Indian pendulum observations have been employed by Colonel Clarke, in combination with those taken in other parts of the globe, to determine the earth's ellipticity. Formerly there was wont to be a material difference between the ellipticities which were respectively derived from pendulum observations and direct geodetic measurements, the former being somewhat greater than $\frac{1}{290}$, the latter somewhat less than $\frac{1}{300}$; but as new and more exact data became available, the values derived from these two essentially independent sources became more and more accordant, and they now nearly agree in the value $\frac{1}{293}$.

As a part of the pendulum operations, a determination of the length of the seconds' pendulum was made at Kew by Major Heaviside, with the pendulum which had been employed for the same purpose by Kater early in the present century, when leading men of science in England believed that in the event of the national standard yard being destroyed or lost, the length might be reproduced at any time with the aid of a reversible pendulum. In consequence of this belief an Act of Parliament was passed in 1824 which defined the relations between the imperial and the seconds' pendulum, the length of the former being to that of the latter—swung in the latitude of London, in a vacuum and at the level of the sea—in the proportion of 36 inches to 39·1393 inches. Thus, while the French took for their unit of length the ten-millionth part of the earth's meridional quadrant, the English took the pendulum swinging seconds in the latitude of London. In case of loss the yard is obviously recoverable more readily and inexpensively by reference to the pendulum than the metre by reference to the quadrant; it is also recoverable with greater accuracy; still the accuracy is not nearly what would now be deemed indispensable for the determination of a national standard of length, and it is now generally admitted that every pendulum has certain latent defects, the influence of which cannot be exactly ascertained; thus the instrument cannot be relied on as a suitable one for determinations of absolute length; but, on the other hand, so long as its condition remains unaltered, it is the most reliable instrument yet discovered for differential determinations of the variations of gravity. In truth, however, the pendulum is a very wearisome instrument to employ even for this purpose, for it has to be swung many days and with constant care and attention to give a single satisfactory determination; thus if such a thing can be invented and perfected as a good differential gravity meter, light and portable, with which satisfactory results can be obtained in a few hours instead of many days, the boon to science will be very great.

The trigonometrical operations fix with extreme accuracy two of the co-ordinates—the latitude and longitude—which define the positions of the principal stations; but the third co-ordinate, the height, is not susceptible of being determined by such operations with anything like the same degree of accuracy, because of the variations of refraction to which rays of light passing through the lower strata of the atmosphere are liable, as the temperature of the surface of the ground changes in the course of the day. In the plains the apparent height of a station ten to twelve miles from the observer has been found to be upwards of 100 feet greater in the cool of the night than in the heat of the day, the refraction being always positive when the lower atmospheric strata are chilled and laden with dew, and negative when they are rarefied by the heat radiated from the surface of the ground. At hill stations the rays of light usually pass high above the surface of the ground, and the diurnal variations of refraction are comparatively immaterial, and very good results are obtained by the expedient of taking the vertical observations between reciprocating stations at the same hour of the day, and as nearly as possible at the time of minimum refraction; but in the plains this expedient does not usually

suffice to give reliable results. The hill ranges of central and those of northern India are separated by a broad belt of plains, which embraces the greater portion of Sind, the Punjab, Rajputana, and the valley of the Ganges, and is crossed by a very large number of the principal chains of triangles, on the lines where the chart shows stretches of comparatively small triangles, which are in most instances of considerable length. Thus it became necessary to run lines of spirit levels over these plains, from sea to sea, to check the trigonometrical heights. The opportunity was taken advantage of to connect all the levels which had been executed for irrigation and other public works, and reduce them to a common datum; and eventually lines of level were carried along the coast and from sea to sea to connect the tidal stations. The aggregate length of the standard lines of level executed up to the present time is nearly 10,000 miles, and an extensive series of charts of the levels derived from other departments of the public service and reduced to the survey datum has already been published.

The survey datum which has been adopted for all heights, whether deduced trigonometrically or by spirit-levelling, is the mean sea level as determined, either for initiation or verification, by tidal observations at several points on the coast lines. At first the observations were restricted to what was necessary for the requirements of the survey, and their duration was limited to a lunar month at each station. In 1872 more exact determinations were called for, to ascertain whether gradual changes in the relative level of land and sea were taking place at the head of the Gulf of Cutch, as had been surmised by the geological surveyors, and observations were taken for over a year at three tidal stations on the coasts of the gulf, to be repeated hereafter when a sufficient period had elapsed to permit of a measurable change of level having taken place. Finally, in 1875, the Government intimated that as 'the great scientific advantages of a systematic record of tidal observations on Indian coasts had been frequently urged and admitted,' such observations should be taken at all the principal ports and at such points on the coast lines as were best suited for investigations of the laws of the tides. In accordance with these instructions, five years' observations have been made at several points, and new stations are taken up as the operations at the first ones are completed.

The initiation of the later and more elaborate operations is due in great measure to the recommendations of the Tidal Committee of the British Association, of which Sir William Thomson was President. The tidal observations have been treated by the method of harmonic analysis advocated by the Committee. The constants for amplitude and epoch are determined for every tidal component, both of long and of short periods, and with their aid tide-tables are now prepared and published annually for each of the principal ports; and further, it is with them that Professor G. H. Darwin made the investigations of the effective rigidity of the earth, which I have already mentioned. The very remarkable waves which were caused by the earthquake on December 31, 1881, in the Bay of Bengal, and by the notable volcanic eruptions in the island of Krakatoa and the Straits of Sunda on August 27 and 28, 1883, were registered at several of the tidal stations, and thus valuable evidence has been furnished of the velocities of both the earth-wave and the ocean-wave which are generated by such disturbances of the ordinarily quiescent condition of the earth's crust.

I must not close this account of the non-graphical, or more purely scientific, operations of the Great Trigonometrical Survey of India without saying something of the officers who were employed thereon, under the successive superintendence of Everest, Waugh, and myself. A considerable majority were military, from all branches of the army—the cavalry and infantry, as well as the corps of engineers and artillery; the remainder were civilians, mostly promoted from the subordinate grades. Prominent shares in the operations were taken by Lieutenant Renny, Bengal Engineers, afterwards well known in this neighbourhood as Colonel Renny Tailyour, of Borrowfield in Forfarshire, of whom and his contemporary, Lieutenant Waugh, Everest, retiring, reported in terms of the highest commendation; by Reginald Walker, of the Bengal Engineers, George Logan, George Shelverton, and Henry Beverley, all of whom fell victims to jungle fever; by Strange, F.R.S., of the Madras Cavalry, whose name is associated with the construction of the

modern geodetic instruments of the Survey; by Jacob—afterwards Government Astronomer at Madras—Rivers, and Haig, all of the Bombay Engineers; Tennant, C.I.E., F.R.S., Bengal Engineers, afterwards Master of the Mint in Calcutta; Montgomerie, F.R.S., of the Bengal Engineers, whose name is best remembered in connection with the Trans-Himalayan geographical operations; James Basevi, of the Bengal Engineers, who so sadly died of exposure while engaged on the pendulum operations in the higher Himalayas; Branfill, of the Bengal Cavalry; Thuillier, Carter, Campbell, Trotter, Heaviside, Rogers, Hill, and Baird, F.R.S., all engineer officers; also Hennessey, C.I.E., F.R.S., M.A., Herschel, F.R.S., and Cole, M.A., whose names are intimately associated with the collateral mathematical investigations and the final reduction of the principal triangulation.

The Trigonometrical Survey owes very much to the liberal and even generous support which it has invariably received from the Supreme Government, with the sanction and approval, first of the Directors of the East India Company, and afterwards of the Secretary of State for India. In times of war and financial embarrassment the scope of the operations has been curtailed, the establishments have been reduced, and some of the military officers sent to join the armies in the field; but whatever the crisis, the operations have never been wholly suspended. Even during the troubles of 1857–58, following the mutiny of the native army, they were carried on in some parts of the country though arrested in others; and the then Viceroy, Lord Canning, on receiving the reports of the progress of the operations during that eventful period, immediately acknowledged them to the Surveyor-General, Colonel Waugh, in a letter from which the following extract is taken:

'I cannot resist telling you at once with how much satisfaction I have seen these papers. It is a pleasure to turn from the troubles and anxieties with which India is still beset, and to find that a gigantic work, of permanent peaceful usefulness, and one which will assuredly take the highest rank as a work of scientific labour and skill, has been steadily and rapidly progressing through all the turmoil of the last two years.'

The operations have been uninfluenced by changes of *personnel* in the administration of the Indian Empire, as Governor-Generals and Viceroys succeeded each other, but have met with uniform and consistent support and encouragement. It may well be doubted whether any similar undertaking, in any other part of the world, has been equally favoured and as munificently maintained.

In conclusion I must state that I have purposely said nothing of the graphical operations executed in the Trigonometrical and other branches of the Survey of India, because they are more generally known, their results appear in maps which speak for themselves, and time would not permit of my attempting to describe them also. They comprise, *first*, the general topography of all India, mostly on the standard scale of 1 inch to the mile; *secondly*, geographical surveys and explorations of regions beyond the British frontier, notably such as are being carried on at the present time on the Russo-Afghan frontier, by Major Holdich and other officers of the Survey; *thirdly*, the so-called Revenue Survey of the British districts in the Bengal Presidency, which is simply a topographical survey on an enlarged scale—4 inches to the mile—showing the boundaries and areas of villages for fiscal requirements; and *fourthly*, the Cadastral Survey of certain of the British districts in the Bengal Presidency, showing fields and the boundaries of all properties, on scales of 16 to 32 inches to the mile. There are also certain large scale surveys of portions of British districts in the Madras and Bombay Presidencies, which, though undertaken originally for purely fiscal purposes by revenue and settlement officers working independently of the professional survey, have latterly been required to contribute their quota to the general topography of the country. And of late years a survey branch has been added to the Forest Department, to provide it with working maps constructed for its own requirements on a larger scale than the standard topographical scale, but on a trigonometrical basis, and in co-operation with the Survey Department. But this brief capitulation gives no sort of idea of the vast amount of valuable topographical and other work for the requirements of the local Administrations and the public at

large—always toilsome, often perilous—which has been accomplished, quite apart from and in quantity far exceeding the non-graphical and more purely scientific work which I have been describing. Its magnitude and variety are such that a mere list of the officers who have taken prominent shares in it, from first to last, would be too long to read to you. Three names, however, I must mention: *first*, that of General Sir Henry Thuillier, who became Surveyor-General on the same day that I succeeded to the superintendence of the Great Trigonometrical Survey, and with whom I had the honour of co-operating for many years; under his administration a much larger amount of topography was executed than under any of his predecessors, and a great impetus was given to the lithographic, photographic, engraving and other offices in which the maps of the survey are published; *secondly*, that of Colonel Sconce, who became Deputy Surveyor-General soon after my accession in 1878 to the Surveyor-Generalship, and with whom I was associated for some years, much to my gratification and advantage, in various matters, but more particularly in the establishment of cadastral surveys on a professional basis at a moderate cost, to render them more generally feasible, which was a matter of the utmost importance for the administration of the more highly populated portions of the British provinces; and *thirdly*, that of Lieutenant-Colonel Waterhouse, who has for many years superintended the offices in which photography is employed, in combination with zincography and lithography, for the speedy reproduction *en masse* of the maps of the Survey, and has done much to develop the art of photogravure, whereby drawings in brushwork and mezzotint may be reproduced with a degree of excellence rivalling the best copperplate engraving, and almost as speedily and cheaply as drawings in pen and ink work are reproduced by photozincography.

Mr. Clements Markham's Memoir on the Indian Surveys gives the best account yet published of the several graphical surveys up to the year 1878. In that year the Trigonometrical, the Topographical, and the Revenue branches, which up to that time had constituted three separate and almost independent departments, were amalgamated together into what is now officially designated 'the Survey of India.' In the same year the chronicle so well commenced by Mr. Markham came to an end on his retirement from the India office—unfortunately, for it is a work of excellence in object and in execution, and most encouraging to Indian surveyors, who find their labours recorded in it with intelligent appreciation and kindly recognition.

During the present meeting, several papers by officers of the Survey will be read —one by Colonel Barron, in person, on the cadastral surveys in the organization of which he has taken a leading share; by Major Baird, on the work of the spirit-levelling which he superintends conjointly with the tidal observations; by Colonel Godwin-Austen, on Lieutenant-Colonel Woodthorpe's recent journey from Upper Assam to the Irawadi river; by Colonel Branfill, on the physical geography of Southern India; and by Colonel Tanner, on portions of the Himalayas and on recent explorations in Southern Tibet. Major Bailey will also read a paper on the forest surveys.

The following Papers were read:—

1. *The Indian Forest Survey.* *By* Major F. Bailey, *R.E., F.R.G.S.*

It is only in comparatively recent times that measures have been undertaken to preserve what remained of the great Indian forests. The first thing to do was to demarcate the tracts which were to be reserved and to free them as far as possible from rights. The area now reserved is about 48,000 square miles, or about $5\frac{1}{2}$ per cent. of the total area of British India, not including the native states. The tracts demarcated owe their immunity from destruction either to the fact that they occupy ground which was, in the absence of communications, inaccessible, or which is much broken, or cannot be irrigated. They are situated either in the plains or on the low ranges of hills rising from them, or on the lower or middle

slopes of the Himalayas up to an elevation of 8,000 or 9,000 feet above sea level. Although they include within their boundaries considerable areas which have been wholly or partially denuded of trees, the ground is generally speaking more or less densely covered with trees and jungle.

In former years accurate forest maps were not required, but the present system of management renders good maps indispensable, and in 1872 measures were taken to provide them. The Imperial Survey Department could not conveniently undertake the work, and it was consequently thought desirable to organise a special branch of the Forest Department to act under the control of the Surveyor-General. This arrangement has worked most satisfactorily. The scale of the maps formed the subject of much discussion, but ultimately it was decided that the scale should usually be 4″ = 1 mile for the most valuable forests, and 2″ = 1 mile for those of less value. An establishment of surveyors was then raised and trained. The first work undertaken was the survey of the forests of Dehra Dun, area about 573 square miles, the non-forest lands of the district being surveyed at the same time by the Imperial Survey Department, and a combined map of the whole country being thus produced. The next work was the survey of the Kumaon and Garhwál forests, area about 1,400 square miles; and the survey of an area of about 1,600 square miles in Haiderabad is now in progress. Altogether since 1872 about 3,000 square miles have been surveyed and mapped, mostly on the scale of 4″ = 1 mile. It will of course take a long time to work over the whole of the forest property, but detailed maps of the entire area are not urgently needed at the present time, since for forests in which simple protection can alone be attempted small-scale maps or sketch maps will suffice for some years to come.

When the survey party takes the field, the officer in charge has command of a considerable number of men, with a large quantity of stores and equipment. He has to hire carts or camels, and march to the scene of the work. On arrival, each native surveyor is given a piece of work, four or five of them being grouped under one European surveyor, and a computing office is established in some central position. When sufficient work of this kind has been done, or when the season is too far advanced for it to be continued, the party moves back to head-quarters. If such work is not well controlled it is sure to show this in inferior quality, insufficient quantity, or high cost. The procedure must be varied according to circumstances, and it has to be considered how a map that will answer the purpose can be produced in the shortest time and at the smallest cost. The ground worked over by the Forest Survey Department presents exceptional difficulties, of which the following are the principal: the surface is much broken up, the crop of trees and jungle is dense, the supply of drinking water is precarious and often of bad quality, the forests are infested with wild animals, food is difficult to obtain, and jungle fever is by no means uncommon. The wild animals are not at all appreciated by the unarmed native surveyors, and many cases have occurred in which they have caused the most serious inconvenience, stopping the survey of certain tracts for a long time. The experience gained of the natives of India in the Forest Survey Department has shown that almost anything can be made of them. The principle adopted has been to stimulate them to exertion and to promote a spirit of emulation among them; they were taught that accuracy was of more importance than rapidity, and encouraged to bring to notice all discrepancies in their work. At first only the most simple operations were entrusted to natives, but a few of them can now do excellent work of the most difficult kind. The combination of European and native labour has answered very well. Detailed surveys of wild and densely wooded ground have rarely been made before in India, and it is evident that they must be more expensive than similar surveys of open, cultivated country; but to provide them is a necessity and a distinct economy.

2. *Account of the Levelling Operations of the Great Trigonometrical Survey of India. By* Major A. W. Baird, *R.E., F.R.S.*

From the origin of the Great Trigonometrical Survey of India until the year 1858 all determinations of relative height were effected by the measurement of reciprocal vertical angles, a method which is based on the assumption that the back and forward angles are equally refracted, in which case the difference of height deduced from them should be exact. But when rays of light passing between two mutually observing stations traverse the lower strata of the atmosphere and graze the surface of the ground, the refraction is rarely identical at both stations even at the same moment of time, and is liable to vary greatly at different hours of the day and at the same hour on different days. Thus determinations of the relative height of stations situated on extensive plains by this method are liable to considerable inaccuracies; and as a belt of plains of great extent—in places several hundred miles broad—intervenes between the hill ranges of Lower and Central India and those of Upper India, and every principal chain of triangles has had to be taken over these plains for a greater or less distance, lines of spirit-levels were initiated, to be carried across them from sea to sea, as a check on the trigonometrical determinations of height. The opportunity was availed of to connect and reduce to a common datum the levels executed in all parts of India for irrigation, railway, and other purposes. Subsequently, when systematic tidal observations came to be undertaken at various points on the coast, lines of level were carried between the tidal stations, to serve as a check on the spirit levelling, and also to connect the tidal stations together.

Every line is gone over by two surveyors working independently of each other, with separate instruments and staves, and comparing results from time to time. The staves have two faces, both graduated in feet and tenths, but one with black divisions on a white ground reading from 0 to 10, the other with white divisions on a black ground reading from 5·55 to 15·55, which gives a useful check against accidental gross errors of reading, as the observer has no bias to repeat on the second face an error made in reading the first. The bulbs of the levels are fitted with graduated scales; the readings of the ends of the bubble are recorded, and corrections are applied for dislevelment, as with astronomical instruments. As there is a tendency to an accumulation of minute constant error in all levelling operations, such tendency is guarded against as far as practicable by alternating the order of the back and forward staff readings at successive stations, and also alternating the direction of operation on successive days or in successive sections of each line.

The rate of progress is not, of course, as rapid as in levelling operations executed with less care and precision, but an average of four miles daily may generally be relied on. Up to the present time 9,680 miles of rigorously executed double line have been completed, and about 300 miles of single line to connect collateral and subsidiary bench marks.

The first five lines which were executed to connect tidal stations indicated, in every instance, that the sea level was apparently higher at the southern than at the northern station. It is quite possible that the level of the surface of the sea may be disturbed under the influence of local attractions, and be higher at some points of a coast-line than at others; but the actual difference of level is only ascertainable approximatively by calculations based on various assumptions regarding the constitution of the earth's crust and the surrounding elements of attraction. It cannot be measured, because the attractions have the same influence on the fluid in the bulbs of the levelling instruments as on the waters of the ocean, when both are equally exposed to their influence; thus, when working along a line of *open* coast the instrumental would coincide with the ocean level, and a large deviation from the normal level of the ocean might exist without any possibility of measuring it. Thus it seemed that the apparent raising of the southern ends of these lines of level must be due not to actual variations in the height of the mean sea, but to some error in the levelling operations. They had been conducted with scrupulous care, and with every conceivable precaution to guard against either accidental gross

error or systematic accumulation of minute constant error; yet a source of minute but cumulative error remained which, coming from an external quarter, was not guarded against by alternating the direction of operation or by any of the expedients adopted for eliminating inherent cumulative errors. It lay in the admitted tendency there is, when levelling an instrument, to unduly depress the telescope in the direction of the light which illuminates the spirit-level of the instrument, thus making all objects viewed through the telescope, when pointed in that direction, appear too high. The sun was the invariable source of illumination, and it was always to the south of the observer, and therefore the southern ends of the lines of levels would have a tendency to be brought out too high. This illumination error is a maximum on the meridian and vanishes on the prime vertical; however great its magnitude, it re-enters and is non-apparent in a circuit of levels; it would only be apparent on lines starting and closing at different points on the mean sea, which gives an independent check on the accuracy of the line of levels. It is a *vera causa* of error such as has actually been met with; but there is now some reason to doubt whether it really was the cause, for the two lines next measured from sea to sea brought the northern ends out highest, and a third line recently completed shows no appreciable difference between the north and south ends. The later results may, however, be due to the observers having been more careful to guard against illumination error. In seven lines out of the eight the discrepancies are small, not exceeding two inches in 100 miles of line; but there is one large discrepancy of $4\frac{3}{4}$ inches per 100 miles, accumulating to 3 ft., on the line between Bombay and Madras. The two weakest sections of this line have been re-levelled, but in each instance with results which were identical with those first obtained. If the observations are errorless in themselves, error must have been introduced by the local attractions encountered on the line which crosses the western ghats and the elevated plateau lying between Bombay and Madras. These attractions would obviously influence the levels of the contiguous instruments in a greater degree than the distant waters of the ocean.

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3. *Notes on the Physiography of Southern India.*[1]
By Colonel B. R. Branfill.

The part of India to which these notes are confined lies to the south of latitude 15°, and mostly in the Madras Presidency. Its principal characteristics are great diversity of feature and mildness of climate, which, though tropical, is almost insular, and entirely subject to the effects of the south-west and the north-east monsoons. It is a region of mountains and hills, elevated table-lands and low-lying flats, fertile plains and barren wastes, flooding rivers with beautiful waterfalls and innumerable artificial lakes, tropical forest, endless groves, and jungly wilderness.

Southern India is an interesting field of observation for the naturalist, and particularly for the physiographer, on account of the elements of change in active operation:—firstly, the decomposing and disintegrating power of the sun's rays, vertical twice every year; secondly, the long-continued violent winds that scour the surface and transport immense volumes of matter to great distances in the air, and, by means of the ocean waves, along the shore; thirdly, the torrents of rain that denude the hill surfaces and score the slopes with deep channels, depositing the spoil on the flooded flats, the growing deltas, and the shoaling shore.

Many other elements of change are at work, and the earthquake alone seems wanting. These agencies seem fully adequate to the task of converting a vast plateau of igneous matter, overlying a granitic base, into the subdued and diversified area we now behold.

For the purpose of these notes the author divides Southern India into three tracts. First, the mountainous region of the Gháts, including the higher tablelands and the great upland plains of Maisúr contained between the Western and Eastern Gháts. Second, the lowlands of the Malabar coast: all that narrow tract of moist sea-board between the foot of the Western Gháts and the Arabian Sea.

[1] Printed in the *Proceedings of the Royal Geographical Society* for November, 1885.

Third, the comparatively dry lowland plains of the Carnatic between the Ghâts and the Bay of Bengal.

The year, for Southern India, is also divided into three seasons: the south-west monsoon, from May to September; the north-east monsoon, from October to February; and the hot season of March, April, and May, between the two monsoons.

The south-west monsoon is shown to be the most important fact and factor of the climate of Southern India. The wind blows very strongly for four months over the Arabian Sea from the south-west. On nearing the coast of Southern India it becomes more of a westerly wind, and retains this direction across the country to the Bay of Bengal. When it strikes the west coast and mounts the barrier wall of the Western Ghâts it drops most of its moisture in torrents of rain, by which the eastward-flowing rivers are flooded as well as the lowlands of Malabar. On the table-lands east of the Ghâts it is strong, cool, and showery, but gradually becomes drier and warmer, and reaches the Coromandel coast as a dry and hot land wind—a veritable *sirocco.* In the Bay of Bengal it regains its northward course, and the cause of its deflection therefrom in crossing Southern India is not quite clear. After a short interval the north-east wind sets in, usually bringing with it some heavy spells of rainy weather, and lasts with little interruption till February. The whole of the country east of the Western Ghâts benefits from these rains, which fill the rivers and reservoirs and moisten the unirrigated tracts sufficiently to enable what is called the cold-weather crop to be grown. The hot season sets in in March, rapidly increasing in intensity till the return of the south-west monsoon. It is tempered, however, by the sea breezes, which are felt far inland. The most agreeable time for visiting India is from October to March; but the naturalist, the physiographer, and the scientific observer need not be deterred by the fear of any danger incidental to a prolonged tour in Southern India, as, by taking advantage of the great variety and agreeable nature of the climates afforded by the high plateaux and hill ranges, the whole year may be spent in a comparatively cool, healthy, and enjoyable climate.

The author suggests a tour which embraces some of the most noteworthy features in the south of India.

Proceeding by sea to Kárwár, near Goa, note about the only sheltered harbour for ships south of Bombay, favourably situated opposite a gap in the W. Ghâts. Landing at Honáwar, observe its fine tidal estuary and the extraordinary surf formed on the bar at the ebb of spring tides. Now ascend the *ghát*, or pass, near here, and visit the splendid Gersappa Falls, where the river Sharávati leaps down at one bound over a sheer precipice 800 feet, in the midst of magnificent wooded mountain scenery. Observe that the Western Ghâts are very steep or precipitous on their western face only, and can hardly be called a range of mountains, but are rather a line of buttresses to the Maisúr highland plateau. The word *ghát* simply signifies a pass or passage, and amongst the natives of India is restricted to that meaning. Proceeding eastwards, visit the high undulating plains of Maisúr, called in the neighbourhood of the Ghâts *Malnád,* or hill country. Bednor, in the Nagar Malnád, the former capital of the local chieftain, a place in ruins now, and almost deserted, is worth a visit to see how soon a town of 100,000 houses and perhaps half a million of inhabitants can be obliterated. After a glance at Maisúr and the Kábéri Falls, the port of Mangalore is visited, to study the shifting of the river mouth and other points of interest, the return to the high lands being made by the next pass up into Kurg (*Coorg*), which for the beauty of its highland scenery and general interest may compare with any such district in the world.

Continuing southwards, the next highland district along the brow of the Ghâts is Wainád, somewhat similar to the Malnád, but not so mountainous as Kurg. It is notable for the British coffee planting industry and the recent gold-mining enterprise.

Thus far the highland districts mentioned are part and parcel of the great central plateau contained between the Western and the Eastern Ghâts. Their general level varies from 2,500 to 3,500 feet above sea, with isolated peaks and masses running up to 5,000 and 6,000 feet. Next comes the Nílgiri plateau, nearly isolated

from the Wainád, at a general altitude of 5,000 to 6,000 feet, and with summits running up to 8,000 feet and upwards. Its undulating grassy surface, splendid climate and scenery are noticed.

The tour is continued to the south of the Nílgiri Mountains, where the high wall of the Western Gháts abruptly terminates, giving place to a wide low passage called the Pálghát Gap, to the south of which the mountains rise again to their full height, and are often termed generally the Southern Gháts. They are more like a true mountain range, springing directly from the low country on all sides. They are not known to contain any large table-land or plateau on their summits, but are broken up into large valleys and lofty peaks, the highest point (Aneimudi), which is also the highest in India south of the Himálaya, attaining 8,838 feet.

Thence the author takes us to the Palani Hills, a peninsular hilly plateau in two steps, somewhat resembling the Nílgiri plateau and the Wainád, then down to the eastern plains with their remarkable red sand-hills drifting like waves before the wind; then south to Cape Comorin, the land's end, and finally round by way of the east coast and Rameswaram to Trichinopoly.

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4. *On a Trip from Upper Assam into the Kampti Country and the Western Branch of the Irrawady River, made by Colonel R. B. Woodthorpe, R.E., and Major C. R. MacGregor. By* Lieut.-Colonel H. H. GODWIN-AUSTEN, *F.R.S.*

Colonel Woodthorpe's recommendation to the Chief Commissioner of Assam to take up again the exploration of the mountainous country in Eastern Assam, and to penetrate if possible beyond the water-parting, having been acceded to by the Indian Government, survey operations were commenced last winter in the valley of the Diúng, or upper waters of the Noa Dihing of the plain country. While engaged on this work, Colonel Woodthorpe, accompanied by Major MacGregor and Messrs. Ogle, Grant, and Latouche, reached the pass of Chanken, 8,300 feet, at the head of the valley, and it was then decided that an effort should be made to visit the Kampti villages on that branch of the Irrawady visited by Wilcox sixty years ago, and never attempted since. It was impossible that the whole party could go, so the three last named returned to finish the survey of the Diúng Valley, while Colonel Woodthorpe and Major MacGregor, who commanded the escort, went on alone. They travelled lightly, with only four sepoys and forty coolies, and in extremely inclement weather, after six days, reached the stockaded village of Langnú, and were well received. They then went on as far as the right bank of the Nam Kiu River, a large tributary of the Irrawady, rising in the snowy range to the northward; it was here eighty yards wide, with long deep pools and rapids. Thence going on to Padao, they saw the chief Rajah, Lukún, of the district, who came from his summer residence to meet them, and he was most friendly, and begged them to stay a month and see all the country. The approaching rainy season rendered this impossible, and they had to start back at once for the Assam side, only doing so just in time, the swollen rivers being far more difficult to cross than on the outward journey. The whole expedition was well planned and carried out, and if the same tact and judgment can be shown in our future relations with these Kamptis, we shall soon know as much of the country on the head waters of the Irrawady as we do now of the Garo, Khasi, and Naga Hills.

Only a very ordinary road is required, crossing some point on the Patkai range, to open up a future trade with these people from the Assam side. And to this may be added the knowledge of the geology, the zoology, and botany of this most interesting region.

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5. *On the complete Exploration of Lake Yamdok in Tibet. By* TRELAWNEY SAUNDERS.

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6. *On Himalayan Snow Peaks. By* Lieut.-Colonel H. C. B. TANNER.

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7. *Notes on recent Mountaineering in the Himalaya.*
By DOUGLAS W. FRESHFIELD, *F.R.G.S.*

SATURDAY, SEPTEMBER 12.

The Section did not meet.

MONDAY, SEPTEMBER 14.

The following Papers and Reports were read:—

1. *Projected Restoration of the Reian Mœris, and the Province, Lake, and Canals ascribed to the Patriarch Joseph.* *By* COPE WHITEHOUSE, *M.A.*

The Berlin Geographical Society has published, in its *Zeitschrift* for May 1885 (No. 116), the latest map of Egypt, from the Fayoum to Behnesa, and from the Nile to the Little Oasis. The text by Dr. Ascherson gives credit for a considerable area to the topographical observations presented to this society at Montreal. So much of the Reian basin as lies between the Qasr Qerūn and the Qasr Reian has not been visited by any European except the author of this paper (1882, 1883). It is now an accepted fact that there is a depression south of the Fayoum, not less than 150 feet below the level of the Mediterranean, with a superficial area at the level of high Nile of several hundred square miles. It is irregular in shape, curving like a horn from a point near Behnesa to the ridge which separates it from the Fayoum. In the southern part are two, and perhaps three, patches of vegetation, wild palm-trees, and ruins of Roman and early Christian date. This part was visited by Belzoni, May 22, 1819; Calliaud, November 24, 1819; Pacho and Müller, 1823–24; Sir G. Wilkinson, 1825; Mason Bey, 1870; and Ascherson, March 27, 1876. Dr. Ascherson determined by aneroid observations that his camp was 29 metres below the sea. Calliaud found ruins about +38 m., or about the level of high Nile in the valley on the same latitude. The aneroid, theodolite, and other observations of March 6 and April 4, 1882, and April 1883, by the author of this paper, established a depth of −175 to −180 English feet. The greatest depth is probably under the western cliffs south of the Haram Medhūret el-Beṛl. No previous explorer had conceived it possible that this might have been a lake within historic times. The level of the ruins, as determined by Calliaud, shows that the ancient station of Ptolemais might have been, as represented in the text and maps of Claudius Ptolemy, on a horn-shaped lake about thirty-five miles long and fifteen wide, with a maximum depth of 300 feet, fed by a canal, partly subterranean, from Behnesa, as well as by a branch of the present Bahr Jūsuf communicating with it through the Fayoum. The lower plain of the Fayoum had been, at that time, fully redeemed, and the present Lake of the Horn reduced to such insignificant dimensions as to be unnoticed. The restoration of the Reian basin of Lake Mœris and the drainage by evaporation of the Birket el-Qerūn would be a repetition in modern times of the best results reached in the Greco-Roman period, perhaps 3,000 years after the first effort to utilise these two unique basins for storage and drainage.

The feasibility of the scheme is partly based upon the Mohammedan traditions in regard to the original redemption of the Fayoum, the construction of the existing canals, and the reservoir of water which formerly filled the Wadi Reian. It had been stated by Sir G. Wilkinson that the Bahr Jūsuf, or Canal of Joseph, owed its name to a restoration under Saladin (*ca.* A.D. 1166). Masūdi (born, Bagdad,

A.D. 885; died, Cairo, A.D. 956) gives in chapter xxi. one of the very numerous forms of the tales in which the principal engineering works of Middle Egypt are assigned to the patriarch Joseph. Joseph also seems to be the Souphis of the Greeks.

It is a question for consideration whether the descriptions of Goshen and the region occupied outside of Goshen proper, and known as the land of Raamses, apply to this part of Middle Egypt. In a posthumous treatise of great critical value, Jablonski of Frankfort (1693–1767) asserted that in Egypt from all time men have been of the opinion that the Israelites dwelt in the present provinces of Beni-Suef and el-Fayoum. Important finds of papyri, and the publication by the Dutch Academy of Sciences of a geographical papyrus of Mœris (of late date, exhibited), its towns and canals, and the Labyrinth, have stimulated the imagination of the archæologist and the historian to a high pitch. The representation of a stately array of cities with emblazoned arms, of fish, aquatic birds, and pasturages for cattle on the western shore, further serves to justify the peculiar admiration expressed for this region by Greek and Roman travellers, as well as by the Semitic historians. The Ionians, Sicilians, and Romans willingly conceded that its public works, in three categories, transcended in splendour and in usefulness the most stupendous efforts elsewhere extant. Their origin was virtually unknown. They were apparently not Egyptian. The Hyk-Sos or Lords of ta-She seem to have been Arabians, who seized upon the strategic advantages of the Fayoum and (in the words of the Nubian geographer, applied to a somewhat similar work in Arabia), made this reservoir not only for the use of the inhabitants, but to keep the indigenous population in greater awe by being masters of the water. Like the Moors in Southern Spain, their works gradually deteriorated in alien hands, and are now, after 4,000 years, at their lowest point. The work of restoration is comparatively easy. The following advantages would result:—First, the lake and morass, now increasing, in the Fayoum would be diminished, and a large amount of land redeemed; second, the danger of an excessive rise of the Nile would be averted, and the labour of taking precautions against it saved; third, a considerable amount of abandoned land, now desert, would be irrigated; fourth, an immense reservoir would deliver water at a high level for navigation as well as irrigation, and even power; fifth, Lakes Menzaleh, Bourlos, Edkou, and Mareotis could be reclaimed, and those parts of the Delta would then again resemble the shores of Holland and the mouths of the Rhine.

2. *Report of the Committee for furthering the Scientific Examination of the Country in the vicinity of Mount Roraima in Guiana.*—See Reports, p. 690.

3. *Mount Roraima.* *By* EVERARD IM THURN.

4. *Report of the Committee appointed for the purpose of promoting the Survey of Palestine.*—See Reports, p. 691.

5. *The Cadastral Survey of India.* *By* Lieut.-Colonel W. BARRON.

The surveyor in India works under various conditions as regards climate and country, and prepares his maps on different scales, to suit the purposes for which the survey is intended.

The Cadastral Survey of India is ordinarily on the scale of 16 inches to a mile, though sometimes on a much longer scale; it has been undertaken to enable the Government to assess the land revenue, and to define the rights of landlords and tenants. About 22½ millions of land revenue is collected yearly, and is assessed in different ways, under both permanent and temporary settlements.

Former field maps were either eye-sketches, or were surveyed with varying degrees of accuracy by non-professional agency, acting under settlement officers,

and the professional survey surveyed the village lands topographically, and determined the exact area of the village as a check on the settlement areas. In 1871 the settlement surveys in the North-West Provinces were made over to the professional surveyors, and since that time various modifications and improvements have been introduced, with the result that the Survey now prepares all the papers and statistics required by the Settlement Department for assessment.

Based on points whose data have been calculated by the Great Trigonometrical Survey of India, the surveyor fixes other points on the boundaries of the villages of a district, and from these again he works down to each individual field, which is the unit of survey. The areas of each village and of each field are calculated, and all the processes are checked and proved throughout.

The proprietary and cultivating tenures are very complicated, and the land is very much cut up by subdivision among the landlords and tenants. The Survey prepares 'records of rights' and 'rent-rolls,' defining the rights and giving the castes of landlords and tenants for each field. It also collects information regarding the rents paid, the crops grown, the nature of the soil, and the means of irrigation, and prepares abstracts of these to guide the settlement officer in his assessments.

The village maps are reproduced by photography, and are also reduced to smaller scales to make up district maps and the atlas of India.

The establishment of a Cadastral Survey during the field season is very large; it is reduced to an office establishment during the hot weather. The yearly outturn ranges from 650 to 800 square miles, comprising sometimes over a million of fields.

Great advantages are derived from the Cadastral Survey, such as stopping litigation about boundaries of villages and fields, defining the rights of landlords and tenants, enabling the Government to know the amount of land under cultivation, and to provide for famines and for the social problems that will be developed in the near future by the great increase of population.

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6. *The Ordnance Survey of Cyprus.* *By* TRELAWNEY SAUNDERS.

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7. *The Rivers of the Punjab.* *By* General ROBERT MACLAGAN, *R.E.*

The country called Punjab receives its name from the rivers which give it its distinctive geographical character. The name, as is well known, means 'five waters,' and they are the five great tributaries of the Indus, namely, Jhelam, Chináb, Rávi, Biás, and Satlaj.

In early times it was called the land of the *seven* rivers, including the Indus itself on one side, and on the other the Saraswati, which was the eastern boundary of the land occupied by the Aryan immigrants from the north (about 1500 B.C.).

The modern British province which we call Punjab—the country marked off for administrative purposes as the charge of the local government—is not thus bounded by the lines of one river system. It includes on one side the strip of country between the Indus and the hills, and on the other a large extent of cultivated plain as far as the Jamna, a river which has different geographical relations.

The seven-river-land (Sapta-Sindu) of the early Aryans had distinct river boundaries, as then understood. The Saraswati, its eastern boundary, presents to us an interesting geographical problem. It is not now such a river as is described in the ancient writings, in which it is mentioned along with the others, and as being of still greater size and importance. Nor can it ever have been a river of the same kind, as it has its source in the low outer hills, while the others come from perpetual snows. Its channel is dry for great part of the year, and it never carries water on so far as to unite with the other rivers. The changes in the country through which it passes may account for a great change of the river. About the sixth century B.C. the Saraswati is said to sink into the earth, and to pass underground to join the Ganges and Jumna at their confluence. This seems intended to describe a river such as it is now.

As a solution of the problem it has been supposed that the Satlaj, instead of turning west at Rúpar and joining the Biás, once ran S.W. by the course of the Saraswati, and that this is the ancient river referred to in the Vedic hymns. It is not impossible that the Satlaj may have once taken this course, but it does not appear that this view can be supported as explaining the difficulty regarding the Saraswati. It is as likely that this river was described in early days on imperfect knowledge of it, perhaps on some occasions when it was seen in flood, and that when the people had advanced beyond it and had become more fully acquainted with it, it was described more appropriately in the later tradition above mentioned.

The Satlaj, whether flowing as at present or by the line of the Saraswati, is the distinct eastern boundary of a great area of hill and plain country enclosed between it and the Indus. These two rivers have their sources within a short distance of each other, on the opposite sides of the same mountain mass, and they unite in the south of the Punjab, the Indus having run a course of about 1,350 miles and the Satlaj about 950. The maximum distance between them, the breadth of the area they enclose, is about 350 miles. The other four rivers are within this ring formed by the Indus and the Satlaj. All of them have certain characters in common, and each certain distinguishing features of its own. Their course among the hills is more or less similar, the Jhelam presenting one special difference; and their hill course, being for the most part in channels with permanent rocky banks and beds, varies little from year to year. In the lower and slower part of their course also they are generally similar, and, like all rivers travelling through alluvial plains, are subject to changes.

These alterations are of two kinds—constructive and destructive. They cut down their banks and they build others. The destruction of high banks is, in floods, by the force of the stream in direct attack, and in the low season by quiet undercutting at the water-level. The matter thus carried off is laid down again, either on the low banks on the opposite side, or in the river, raising shoals and islands, or across the mouths of branch channels, blocking them up and laying them dry. All this is familiar to people in other parts of India and in other countries where great rivers traverse similar plains. There are long stretches of the Mississippi banks which exactly resemble those of the Indus, and which the river treats in exactly the same way. Something can be done, and is done when necessary, to check the erratic movements of rivers endangering property of value. Protective and directing works have at different times been carried out on the Indus, the Rávi, and the Satlaj. Besides changes of channel and destruction of banks when a main stream takes to oblique courses, a river keeping a straight course is liable in flood to cut deep furrows in its bed. Thus the Satlaj a few years ago brought down one pier of the railway bridge, sunk to a depth of 70 feet, by scooping out the bed below it.

The changes of river channels and of the direction of the main stream are unfavourable to navigation. In the Punjab steam navigation has practically been discontinued on all the rivers except the largest, namely, the lower Indus, and the combined Jhelam, Chináb, and Rávi, up to Multan. River conservancy, in the sense of works for keeping open certain channels for navigation, is too costly for application on a large scale. It is found better, where steam navigation is kept up, to maintain local pilotage. Though they are not well suited for steam navigation, there is extensive boat traffic on the Punjab rivers. And on the Jhelam and Chináb, near the foot of the hills from which the pine timber comes, there is constant boatbuilding for the lower Indus.

In 1841, and again in 1858, there were very striking and serious floods in the Indus, caused by temporary obstruction of narrow gorges in the hills. In both cases warning came (but was not fully understood) by the river at Attak falling when it should have been rising. The effect, when the barrier gave way, was very remarkable and very destructive. In 1858 the Kabul River was driven back by the immense volume and force of the released Indus, which flowed up stream as far as the British station of Naoshera, which was inundated and destroyed.

The Indus, when it reaches the plains, has a temperature in winter about 5° below that of the air. The difference in summer, when the river is being fed by

melting snows, is about 14°. At a great depth the difference is greater, a circumstance which is turned to practical use at Attak.

The fall of these rivers being greatest in the hill portion of their course, and decreasing as they come down through the plains, the vertical section of their course is a curve terminating in a nearly horizontal line at the sea. From Attak to Kalabagh the fall of the Indus is 50 inches per mile, from Kalabagh to Mittan Kote 12, and from Mittan Kote to the sea 6, the end part being less. The result is a constantly increasing tendency to deposit silt and raise the bed, and by overflow to raise the banks. For a great part of its course the Indus flows in a channel slightly above the level of the land on either side.

The local rainfall of the country through which these rivers flow in the Punjab diminishes gradually in quantity from their first entrance on the plains to the place of their junction above Mittan Kote. The Chináb issues from the hills in a region of 51 inches annual rain, the Indus and the Jhelam 36, the Rávi and the Biás 53, the Satlaj 26; and their common confluence is in a tract of country which has no more than 6 inches rain in the year. The great floods which they all bring down in the rainy season are of course chiefly due to the more copious rainfall in the hill country from which they come. To meet in some measure the local want of water thus increasing southward, the rivers are made to give off part of their supplies in canals, which fill as the river rises. Canals, carrying water permanently throughout the year, are drawn off from some of the rivers in the upper part of their course near the foot of the hills, and are carried along high land for the supply, all the way, of the country right and left. So great areas of land are protected against the possible effects of their scanty and precarious rainfall. Where these canals and their branches flow, the level of water in the wells is raised, and thus more advantage can be taken of the great sheets of water at varying depths below the surface. In the country through which run the dry channels of the Saraswati, Gaggar, Markanda, &c., the depth of the wells is very great, but the rainfall, though small (about 18 inches), is much greater than in the country to the west, at the tail of the Punjab rivers.

Besides the windings and changes of channels for short distances, with general maintenance of the same line, there are deviations on a larger scale, rivers forsaking old lines and taking an entirely new course. One well-known instance of this among the Punjab rivers is that of the Rávi, of which a deserted channel is traceable for a long distance in the Lahore and Montgomery districts.

The Punjab rivers are of different colours, depending on the soil through which they have passed and the tributaries they have received. The different colours of two rivers is often observable for a long distance below their confluence. The Indus below Attak is dull blue; its tributaries in this part of its course are red, except the Harro, which is light in colour and comparatively clear. The Ghana (Satlaj) is light but not clear where it is joined by the red Chináb, and they run on for a long way not mixed.

The united rivers which join the Indus are of less volume and velocity than its single stream. The width of the Panjnad (the combined five) is more than twice that of the Indus, but its depth is smaller and the rate of its current less than one-half. In the low season the discharge of the Indus is 92,000 cubic feet per second, and of the Panjnad 69,000—in all 161,000. The flood discharge in the month of August below the junction has been estimated at 446,000 cubic feet.

Such rivers are great powers, very valuable, and difficult to deal with. By watching their characters, and obeying while controlling the action of nature, we can do much to make them subservient to our purposes, and in some measure to illustrate man's influence on the physical as well as political geography of a country.

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8. *On a Clinometer to use with a Plane-Table. By* Major Hill.

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9. *On a supposed Periodicity of the Cyclones of the Indian Ocean, south of the Equator. By* Charles Meldrum, *F.R.S.* —See Section A, p. 925.

10. *The Portuguese Possessions in West Africa.* *By* H. H. JOHNSTON.

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11. *North-west Australia.* *By* J. G. BARTHOLOMEW.

TUESDAY, SEPTEMBER 15.

The following Papers were read:—

1. *Antarctic Research.*
By Admiral Sir ERASMUS OMMANNEY, *C.B., F.R.S., F.R.G.S.*

The object of this paper was to draw attention to the neglect of the Antarctic region as a field for exploration. The author gave a summary of the work which has already been done by Cook, Bellingshausen, Weddell, Biscoe, Balleny, Wilkes, Dumont d'Urville, James Ross, and Nares (in the *Challenger*), and referred to a paper by Dr. Neumayer on the subject, the substance of which was reproduced in 'Nature,' vol. vii. The author concluded as follows:—'I have thus laid before you but a very imperfect description of these voyages; to give the details of the scientific results would occupy a separate paper. But I have endeavoured to demonstrate how large a field remains open for discovery. I think, from all we now know, we may infer that the South Pole is capped by an eternal glacier; and, from the nature of the soundings obtained by Ross, it would appear that the great ice-wall along which the ships navigated was the termination of the glacier—the source from which the inexhaustible supply of icebergs and ice-islands are launched into the Southern Ocean, many of which drift to the low latitude of 42°. The fact of finding the volcanoes of equal proportions to Etna or Mont Blanc creates a zest for further research regarding that awful region on which neither man nor quadruped ever existed. No man has ever wintered in the Antarctic zone. The great desideratum now before us requires that an expedition should pass a winter there, in order to compare the conditions and phenomena with our Arctic knowledge. The observations and data to be collected there throughout one year could not fail to produce matter of the deepest importance to all branches of science. I believe that such an achievement can be accomplished in these days with ships properly designed and fitted with the means of steam propulsion; nor is it chimerical to conceive a sledge party travelling over the glacier of Victoria Land towards the South Pole, after the example of Nordenskjöld in Greenland.

'Another interesting matter requires investigation, from the fact that all the thermometers supplied for deep-sea temperatures to Ross were faulty in construction, as they were then not adapted to register accurately beneath the weighty oceanic pressure. Moreover, another magnetic survey is most desirable, in order to determine what secular change has been made in the elements of terrestrial magnetism after an interval of forty years and more, when taken by Ross. In fact, there exists a wide field open for investigation in the unknown South Polar Sea. This paper will, I trust, be the prelude for others to follow in arousing geographers and this powerful Association in promoting further research by despatching another South Polar expedition, having for its object to secure a wintering station. No other nation is so capable of providing and carrying it out. Even in the Australian colonies there exists the spirit and the means for such a noble enterprise.' And he also directs the public attention to the fact that the only scientific information yet procured in the South Polar region within the Antarctic circle is limited to the observations collected by the *only* expedition ever despatched from this nation expressly for scientific research.

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2. *Geographical Education.* *By* J. Scott Keltie.

The author mainly confined himself to the chief points in the Report on Geographical Exploration which he recently presented to the Royal Geographical Society. In this country, he stated, the position of geographical education is in a hopeful condition in elementary schools. The programme prescribed by the Education Department is satisfactory, and teachers seem to be practically getting into the way of carrying it out efficiently.

In the chaotic mass of middle class schools the position is far from satisfactory. The previous efforts of the Society and of the Oxford and Cambridge local examinations have had a beneficial influence, and numerous teachers here and there are found who recognise the educational value of geography, and do their best to teach it adequately. But as a rule it scarcely counts at all as a subject of education. This partly arises from the overcrowded state of school programmes, and partly because teachers themselves are ignorant of the subject and have no taste for it. The higher we ascend in the various grades of schools, the less do we find geography attended to. It appeared to the author that the wretched place which geography holds in our schools, and the barren results which in too many cases follow its teaching, is largely due to the narrow conception which prevails of what is known as political geography. Until we got beyond this fruitless conception of the subject, until we came to realise that political geography is really the resultant of ever so many factors, of the interaction not only between man and man, but between man and his physical surroundings, and until teachers are trained to bring the subject in this aspect before their pupils, it will never be other than the dull barren task it now is. (The paper is published in full in the 'Scottish Geographical Magazine,' October 1885.)

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3. *On Overland Expeditions to the Arctic Coast of America.* *By* John Rae, *M.D., LL.D., F.R.S., F.R.G.S.*

Hearne, 1771.

There are records as early as 1715 that information was brought to the Hudson's Bay Company's fort at Churchill, Hudson's Bay, by the Indians, of there being a great river falling into the Arctic Sea many days journey to the northwest, the banks of which abounded in minerals, and the Indians frequently brought pieces of pure copper said to have been found there.[1]

It was to see these copper-mines, and also to get to the Arctic Sea, that Hearne made a very long journey with Indians, who treated him with great indignity and contempt, and he met with much suffering and privation, besides witnessing a horrible massacre of poor Eskimos by his savage companions, being unable to save even one poor young girl, that was stabbed to death whilst clinging to his knees for protection. Hearne certainly reached the Arctic Sea, but his survey was so inaccurate that he placed the mouth of the Coppermine River 228 geographical miles too far north and 110 geographical miles too far west, so that his map was *worse* than useless.

McKenzie (afterwards Sir Alexander), 1789.

The Arctic Sea was next 'tapped' by McKenzie in 1789. He descended the magnificent river that so worthily bears his name in a bark canoe, the crew feeding themselves chiefly by fishing and shooting. He arrived at an island in latitude 69° N., near the shore of which he saw many white whales (*Beluga*) with indications of a rise and fall of tide, and came to the conclusion that he had reached the mouth of the river, in which belief he was found to be correct. In fact, all his positions were found to be as satisfactory as those of Hearne were the reverse.

[1] To this day all weapons and tools of the Eskimos near the Coppermine are made of copper.

Franklin, Richardson, Back, and Hood, 1821.

Thirty years elapsed before the Arctic coast was again visited by an overland Arctic expedition, one of the most disastrous and pitiable ever known, although commanded by one of the best and bravest of men, assisted admirably by Dr. Richardson, a man gifted with all kinds of scientific knowledge and numerous other sterling qualities, that so peculiarly fitted him for the position of medical man and naturalist to the expedition.

Leaving England in 1819, two summers' travelling by boats and canoes through the Hudson's Bay Company's territory took the party in 1820 to winter quarters, named Fort Enterprise, some distance north of Great Slave Lake. On opening of the navigation in spring 1821 two canoes descended the Coppermine River and turned eastward, the object being to trace the coast as far as possible in that direction with the hope of meeting Parry, who about that date was exploring with two ships on the east coast of Melville peninsula, in hopes of finding a passage westward.

For five weeks the expedition struggled gallantly on, hampered by ice, stopped by storms, and on 'short commons' for food, but making only 150 miles easting. Parry at the time was more than 600 miles farther east. The canoes were abandoned in Hood River, and two small ones (a *mistake*) made out of them for crossing streams, &c. On the last day of August they began the overland journey towards Fort Enterprise, which in a straight line was 170 miles distant. The sufferings and privations from cold and hunger were simply terrible; much of their food was a very unpalatable lichen (*tripe de roche*), with short allowance of roasted bones and skin. The men's loads were so heavy [*foolishly so*—J. R.] that when they did kill large game little or none of the meat could be carried on.

Ten of the party perished miserably, two of these being shot—the one murdered, the other the murderer.

All the officers except poor Mr. Hood got back to England safe and well, after having been treated by the Indians—who brought them food when at death's door —'with a kindness and humanity that would have done honour to the most civilised of peoples.'

Franklin and Richardson, Back, and Kendall, 1826.

This expedition was as successful as the former one (1821) was unfortunate. Winter quarters were at Fort Franklin, Great Bear Lake. Four boats descended the McKenzie in spring 1826, and separated near the mouth of the river, becoming actually two expeditions, Franklin and Back in two boats going to the west, whilst Richardson and Kendall took the opposite direction, their destination being the Coppermine River, which they reached without difficulty, left their boats and walked overland to Bear Lake, where there was a boat waiting, in which they took passage to Fort Franklin. The western party were not so fortunate, having been compelled to turn back when 160 miles short of Point Barrow, to which place the barge of H.M.S. 'Blossom' (Captain Beechey) had come from the west the same season. The expedition got back to England in 1827.

Back, 1833-34.

In 1832 much anxiety began to be felt for Sir J. Ross's expedition to the Arctic in the little vessel 'Victory,' which left England in 1829, and a party under Captain Back was sent overland to search for them by way of the Great Fish River. Whilst wintering at the east end of Great Slave Lake in 1833-34 news was received that Sir J. Ross had got home; nevertheless, Back went down the river named after him, and explored more than 100 miles of the coast near its mouth, then returned to Fort Reliance, where another winter was spent, and returned to England the following summer (1835).

Hudson's Bay Company's Expedition, under Dease and Simpson, 1837, 1838, and 1839.

Several parts of the coast still remained untraced, and two of these gaps were completed in a very satisfactory manner by the above expeditions. In the first

year (1837) the 160 miles to the west—which Franklin could not reach—were traced. In the two following years, partly on foot, but chiefly in boats down the Coppermine, they went east, even *beyond* Back's survey of the mouth of the Fish River, thus accomplishing a boat voyage of more than 1,400 geographical miles, the longest ever made in boats on the Arctic coast, on which they remained until September 16, a dangerously late period. Dease and Simpson's tracing of new ground amounted to 667 geographical miles, but to do this 800 miles of previous survey had to be gone over. Simpson was awarded the Royal Geographical Society's Gold Medal when less than half his Arctic work was accomplished.

Rae, 1846–47, 1850–51, and 1853–54.

The first and last of these expeditions were equipped in 1846 and 1853 at York Factory, and wintered at Repulse Bay on the Arctic circle; the first in a stone house, the last in a snow-hut, which proved by far the more comfortable of the two, although they had no fire to give warmth in the one, nor a 'fire-lamp,' such as the Eskimos use, in the other. In the stone house the temperature fell 15° or 20° during the cooking of our two meals—frequently only one—per day, as the door had to be kept open to allow the smoke to escape which would not go up the chimney. The first party consisted of Rae, ten men and two Eskimos; the last of eight persons. On each occasion venison and fish sufficient for eleven or twelve months were obtained, nearly half the deer for winter use being shot by Rae. In 1847 the first long sledge journeys ever made on the Arctic shores of America were performed, more than 1,200 miles in distance, uniting Ross's discoveries on Boothia with those of Parry on Melville peninsula, all but a few miles.[1] The cost of this expedition was less than 1,400*l.*

In 1854 a sledge journey of about 1,100 miles, at the rate of nearly 20 miles a day, was made, uniting the surveys of Dease and Simpson to those of Ross, west of Boothia, and proving King William's Land to be an island. The work done by these two expeditions was the tracing 933 miles of new land, the obtaining of the first information (in 1854) of the fate of the Franklin Expedition, and the making four voyages of 900 miles each in open boats along a dangerous coast, all at a cost of less than 3,000*l.* for both.

In 1850 Rae, whilst in charge of McKenzie River District, was asked by the Admiralty to go in search of the missing expedition, and to take any route he thought best. There was only one route open, that by Great Bear Lake and the Coppermine River, which could not be utilised until 1851, as small boats had to be built suitable for hauling overland. It was confidently stated that no wood fit for boatbuilding could be obtained on the east side of Great Bear Lake, yet this difficulty was overcome, and Indians as hunters were searched for and found. Two nice little boats were built by the carpenter, who, although a good workman, did not know the form of boat required, so Rae's experience of many years before in the Orkney Islands became useful, as he not only drafted the boats to scale in every plank, but cut out and roped the sails, and fitted and spliced the rigging and other gear.

A sledge journey of more than 1,000 miles was made by Rae, two men, and three half-starved dogs, to the coast and along Wollaston Land, at the rate of 24 miles a day, all the party hauling or carrying loads the whole way. The boat voyage to the eastward of the Coppermine was 1,350 miles, partly along the coast of Victoria Land, and up Victoria Strait to a higher latitude than that where Franklin's ships were abandoned in 1848, near King William's Island, on the east side of the strait, which was filled with immense heaps of rough ice in 1851. On returning to the Great Bear Lake an effort was made to get south before the closing of the river navigation, but the boat was frozen up in Athabasca River. From this place the party travelled on snowshoes 1,300 miles (at the rate of 27 miles a day) to Red River[2] where all the men were paid off except two, who accompanied Rae to the United States 450 miles in ten days, being aided by dogs.

[1] A slight error in the chart, which was relied upon as correct, gave to Parry's Survey a few more miles than was correct.

[2] Gold medal of R. G. S. awarded in 1852.

As the searching expeditions of Richardson and Rae, in 1848, of Rae, 1849, of Pullen, 1849–50, and of Anderson and Stewart, 1855, obtained no new geographical results, no details are given of these.

APPROXIMATE AMOUNT OF GEOGRAPHICAL WORK DONE BY THE EXPEDITIONS NORTH OF ARCTIC CIRCLE UNDER—

			G. M.		G. M.	G. M.
1821.	Franklin & Richardson	on foot	35	in canoes	415	450
[1] 1826.	" "	"	90	in boats	955	1,045
				Total		1,495
1834.	Back	in boat on river	120	in boat on coast	105	225
1837. [2] 1838. 1839.	Dease & Simpson (H. B. Co.)	on foot	95	in boats	722	817
1847. [3] 1851. 1853–4.	Rae (H. B. Co.)	sledging on foot	1,123	in boats	369	1,492
				Grand total		4,029

4. *On the best and safest Route by which to attain a High Northern Latitude.* *By* JOHN RAE, *M.D., LL.D., F.R.S., F.R.G.S.*

The plan proposed is that the route by the west shore of Spitzbergen should be taken by one, or perhaps two, steamers similar to the fine vessels used in sealing and whaling at the present time. That after forcing the ice 'pack' at the north-west end of Spitzbergen, a north-east course towards Francis Joseph Land should be followed. That a depôt of coals should be placed at a convenient harbour in North Spitzbergen. Extracts are given from Parry's 'Narrative,' 1827, pp. 101 and 148, showing how open and small the ice was in latitude 82° 45′ N. The southern drift of the ice that so obstructed the advance of Parry's boats will be no great impediment to a powerful steamer, whilst if she gets helplessly fixed in the pack she will drift homewards with it. No well-equipped and powerful steamer has tried this route.[4]

5. *Oceanic Islands and Shoals.* *By* J. Y. BUCHANAN.

6. *On the Depth of the permanently Frozen Stratum of Soil in British North America.* *By* General Sir J. HENRY LEFROY, *K.C.M.G., F.R.S.*

7. *On Recent Explorations in New Guinea.* *By* COUTTS TROTTER.

The author desired to bring our knowledge of the country up to date by some notes on what has been done there since 1883, when he read a paper on New Guinea before the Association. He calls attention to the results of Mr. Chalmers's journeys in the south-eastern peninsula, which have added considerably to our knowledge of the physical features of the region. Proofs have been found near Yule island of intercourse with the inhabitants of the northern coast, and this, coupled with native reports, leads to the belief that a route across the country will

[1] Actually two expeditions, one east, the other west.

[2] Dease and Simpson had to pass over about 800 miles of previously traced coast before getting to new ground, but Franklin and Richardson were on new ground at once on reaching the coast.

[3] Of the coast, &c., traced by Rae, 1,123 miles were done by sledging, believed to be the most laborious of Arctic work.

[4] Parry found the ice floes so small in latitude 82° 45′ N, that only one piece could be found large enough and strong enough to haul his boats upon.

be found in that direction. The numerous so-called 'temples' found near the head of the Gulf of Papua, with a priestly class attached to them, is remarkable, and argues a decided mixture of race, pointing in fact to the prevalence of Polynesian as opposed to Papuan religious ideas.

After referring to the hydrographical problems suggested by the character of the country on the Gulf, and further west, at Onin, Mr. Trotter discusses the probable importance of the recent ascent of the Amberno river, an account of which, translated from the Dutch, was contributed by him to the Royal Geographical Society's Proceedings for March last. He adds some notice of surveys by the Germans of the territory recently annexed by them, parts of which opposite to the island of New Britain appear to offer a fairer prospect to settlers than any other district as yet discovered in New Guinea.

The author takes an unfavourable view of the effect on the interests of the natives of the conflicting jurisdictions, and differing ways of treatment, to which they will now be subjected. This paper will be found *in extenso* in the 'Scottish Geographical Magazine' for October, 1885.

WEDNESDAY, SEPTEMBER 16.

The following Papers were read:—

1. *On Journeyings in South-Western China. By* A. HOSIE.

In the autumn of 1881 Mr. Hosie was appointed Her Majesty's Agent in Western China, and reached Ch'ung-ch'ing, in the province of Ssŭ-ch'uan, in January 1882. From this point he made three journeys in South-Western China. In the spring of 1882 he proceeded through Southern Ssŭ-ch'uan and Northern Kuei-chou, the Chinese 'Switzerland,' to Kuei-yang Fu, the capital of the latter province, whence he journeyed westward in the footsteps of Margary to the capital of Yünnan. From Yünnan Fu he struck north-east through Northern Yünnan, following for days here and there the routes of Garnier and the Grosvenor Mission. At last he descended the Nan-kuang River and reached the right bank of the Great River, the local name of the Upper Yangtsze, at a point below Hsü-chou Fu, an important city at the junction of the Min River and the Chin-sha Chiang, or River of Golden Sand. Here he took boat and descended the Great River to Ch'ung-ch'ing, his starting-point.

In February 1883 Mr. Hosie again left Ch'ung-ch'ing, and proceeded north-west to Ch'êng-tu, the capital of the province of Ssŭ-ch'uan, by way of the brine and petroleum wells of Tzŭ-liu-ching. From Ch'êng-tu he journeyed west and south-west through the country of the Lolos, skirting the western boundary of Independent Lolodom. From Ning-yüan, locally called Chien-ch'ang, and lying in a valley famous, among other things, as the habitat of the white-wax insect, he passed south-west through the mountainous Cain-du of Marco Polo, inhabited in great part by Mantzŭ tribes, and struck the left bank of the Chin-sha Chiang two months after leaving Ch'ung-ch'ing. From this point Ta-li Fu, in Western Yünnan, was easily reached. From Ta-li Fu Mr. Hosie journeyed eastward to Yünnan Fu, which he had visited the year before, and then struck north-east through Western Kuei-chou to the Yung-ning River, which he descended to the Great River. Lu Chou, an important city at the junction of this river with the T'o River, was soon reached, and the Great River was again descended to Ch'ung-ch'ing. This journey occupied four months.

In June 1884 Mr. Hosie again left Ch'ung-ch'ing, and from Ho Chou, a three days' journey to the north of that city, he struck westward through a beautifully cultivated and fertile country to Chia-ting Fu, on the right bank of the Min at its junction with the T'ung River. Chia-ting is famous as the great centre of sericulture in Ssŭ-ch'uan, and as the chief insect wax producing country in the Empire.

A day's journey west of Chia-ting is the famous Mount O-mei, rising 11,100 feet above the level of the sea. This mountain, which is sacred to the worship of Buddha, Mr. Hosie ascended in company with crowds of pilgrims. He then proceeded south, skirting the eastern boundary of Independent Lolodom, to the River of Golden Sand, the left bank of which was struck at the town of Man-i-ssŭ, between forty and fifty miles above P'ing-shan Hsien—the highest point reached by the Upper Yangtsze Expedition in 1861. From Man-i-ssŭ Mr. Hosie descended the Chin-sha Chiang and the Great River to Ch'ung-ch'ing.

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2. *Notes on the large Southern Tributaries of the Rio Solimoes or Upper Amazon in Brazil, with special reference to the Rio Jutahi. By* Professor J. W. H. TRAIL.

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3. *The Depth and Temperature of some Scottish Lakes. By* J. Y. BUCHANAN.

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4. *On the Geographical Features of the Beauly Basin. By* THO. W. WALLACE.

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5. *What has been done for the Geography of Scotland, and what remains to be done.*[1] *By* H. A. WEBSTER.

After explaining that he wished rather to offer a few practical suggestions for the future than to be the mere chronicler of the past, he gave a brief sketch of the various contributions made to the map of Scotland previous to the establishment of the Ordnance Survey, calling attention more especially to the wonderful peregrinations of Timothy Pont, a reproduction of whose maps and notes in their entirety would be worth the attention of some of our publishing societies. He next proceeded to point out that, admirable as the labours of the Ordnance Survey admittedly were (and, for one thing, they for the first time enabled the geographer to form a true idea of the vertical development of the country), they could not be considered complete until certain *lacunæ*, especially as regards altitudes, were filled up, and until the general results were rendered more readily available by being co-ordinated in an official handbook. The parochial character of the details registered in the area-books of the survey rendered them practically useless to the geographer. Even were he content to accept the parish as the unit of description (and a more absurd one could hardly be found), it was only by a tedious arithmetical process he could discover how much of this area was occupied by land and how much by water, how much was arable and how much forest. To all such questions as, What is the length of this river? What is the extent of its basin? To what distance is it navigable? To what distance does the tide ascend? How much of this or that area lies between 500 and 1,000 feet? how much between 1,000 and 1,500 feet? and so on, the maps of the Survey might be said to contain the answers, but in most cases they contained them, so to speak, only in solution. No *accurate* measurement, for example, appeared to have been made of the river-basin areas; and, according to Mr. Stanford's estimate, it would cost a private person 20*l.* to get the necessary operations performed. Even the accurate measurement of all the development lengths of the rivers would be a tedious task. But to several of the questions which the geographer naturally asks the Ordnance Survey maps supplied no answer in any form. We had the altitude of many of the lakes, but for some of the more important ones no precise figures were given. In some cases the area-books of the parishes enabled us to find the areas of the lakes; in other cases they did not. In regard to the depth of our lakes and rivers—and the submerged portion of a valley is geographically as interesting as the sub-aërial portion—absolutely no

[1] Printed *in extenso* in *The Scottish Geographical Magazine*, October 1885.

data were supplied by the Ordance Survey. Nor, with a few individual exceptions, did they exist in an accurate and trustworthy form anywhere else. It was an open secret that, when this omission was pointed out to the Government by the Royal Societies of London and Edinburgh, the Lords of the Treasury refused, and again refused, to authorise a bathymetric lake and river survey being carried out, either by the officers of the Ordnance Survey or by those of the Hydrographic department. Such a refusal could not be permanently accepted. It was to be hoped that when the Government was next urged to move in the matter they would be asked for more, and not for less. We required not only a hydrographic survey done once and for all (though that was worth the doing); we required a systematic registration of hydrographic facts throughout the country, in order that the true *régime* both of lakes and rivers might be known in detail and with scientific precision. The ignorant niggardliness of the British Government was in striking contrast to the conduct of those of some foreign countries. In Switzerland, for instance, there was a regular system of inland hydrographic observations, by which the *régime* of all the principal rivers was annually recorded and rendered easily intelligible by a series of graphic bulletins. In regard to a Swiss river, we could tell the volume at any period of the year at several important points, and could compare the facts of 1884, for instance, with those of any year in the last two decades. Everyone knew what a vast body of interesting data had for generations been accumulating about such rivers as the Po and the Rhone, and many had no doubt heard of the system of hydrographic stations recently established by the Italian Government in the basin of the Tiber. Why should we not endeavour to learn something definite and precise about the character of our own rivers? The investigation was only the natural complement on the one hand of the physical structure of the country, and on the other hand of its meteorology. Our Scottish Meteorological Society had now succeeded in establishing meteorological stations throughout the country; let hydrographic stations bear them company along our principal rivers. Rainfall and river discharge were mutually illustrative. Another matter, not so directly of geographic import, might be mentioned in passing—the investigation of the different chemical qualities of the waters of the different lakes and rivers. But, to proceed to a strictly geographical matter, it had been frequently pointed out that unfortunately the results of the coast surveys had not been incorporated in the seaward portions of the Ordnance Survey maps; nor, indeed, was the submarine portion of our island group sufficiently attended to in any of our physical maps. A special interest attached to the hollow of the North Sea, but a good deal remained to be done before the demands of modern research would be satisfied. Good work was happily beginning to be carried on at Granton and elsewhere in regard to the difference of salinity, &c., between the water of this almost land-locked basin and that of the open Atlantic.

Turning from the physical to the political or administrative geography of Scotland, the reader briefly called attention to the fact that while we had elaborate studies of the Ptolemaic geography of the country, and attempts such as those of Cosmo Innes, to reconstruct the civil and ecclesiastical divisions of certain periods, the detailed history of the rise of the Scottish counties, and of the fixing of the Scottish-English border would furnish subjects for difficult but interesting investigation. He then referred at some length to the desirableness and possibility of collecting and elucidating the whole *corpus* of Scottish place-names. Important studies in this department had been already made by Dr. Skene, Captain Thomas, and others; but what was now wanted was a complete system of registration, and a co-operative system of historical and philological illustration. Of such a treatment of national place-names the Netherlands afforded a most instructive example. The Publications Committee of the Scottish Geographical Society was endeavouring to organise a special committee in connection with the subject. In conclusion, though it might be said that the subject was rather sociological than geographical, attention was called to the necessity of a greater application of cartography to the rendering of statistical facts, such as those of density of population, birth and death rates, distribution of trade and commerce, education, &c. Augustus Petermann, at the census of 1851, set an admirable example to our census authorities,

but they failed to follow it. One could actually get a clearer idea of the relative density of the population throughout the different parts of the United Kingdom from Petermann's map than from anything that had since been published. In this matter of applied cartography, Scotland (and it might be added England also) was deplorably behind most foreign countries—notably Germany, France, and Italy. To some extent this might be the fault of the cartographers, but to a larger extent it was due to the small attention that was bestowed on the *systematic* collection of statistical information in such a form as can be tabulated or 'graphicised.' Nothing was more difficult in many cases than to obtain statistical facts for any smaller totality than the United Kingdom. It was time that an attempt should be made to compile, under the auspices of some authoritative institution, such as the Royal Society of Edinburgh, a new statistical account of Scotland: though such a work as Mr. Groome's 'Ordnance Survey Gazetteer' did much to supply the desideratum, the enterprise was too difficult for private accomplishment.

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6. *On Bathy-hypsographical Maps, with special reference to a Combination of the Ordnance and Admiralty Surveys. By* E. G. Ravenstein, *F.R.G.S.*

The bathy-hypsographical map, which exhibits the vertical configuration of the solid surface of the earth above as well as below the ocean-level, is a product of modern times. It was Gerard Mercator who first inserted soundings upon a chart in 1585, but nearly two centuries passed away before Cruquius, in 1728, introduced the fathom-lines with which we are all familiar. Buache, and after him Ducarla, first suggested the introduction of contours upon maps, and their idea was realised in 1791 by Dupain-Triel on a map of France. The combination of these two descriptions of contoured maps we owe to modern German geographers, and more especially to Berghaus, von Sydow, and Ziegler. Cartographers in effecting this combination had hitherto quite lost sight of the fact that the heights on maps are referred to high or mean water, whilst the depths on charts represent soundings reduced to low water. This rough method gave satisfactory results when dealing with maps on a small scale, but a more rigid method would have to be applied when it was desired to combine accurate surveys like those made by the Ordnance and Admiralty departments. The so-called mean level of the sea was not a suitable datum level, and it would be necessary to carry on tidal and other scientific observations on a far more comprehensive plan than had been done hitherto if a really satisfactory bathy-hypsographical map of the British islands were to become attainable. These various supplementary surveys, tidal observations, &c., it was to be hoped, would expand into a comprehensive scientific survey of the British seas.

SECTION F.—ECONOMIC SCIENCE AND STATISTICS.

PRESIDENT OF THE SECTION—Professor HENRY SIDGWICK, M.A., Litt.D.

THURSDAY, SEPTEMBER 10.

The following Report and Papers were read:—

1. *Report of the Committee for continuing the inquiries relating to the Teaching of Science in Elementary Schools.*—See Reports, p. 692.

The PRESIDENT delivered the following Address:—

I HAVE chosen for the subject of the discourse, which by custom has to be delivered from the chair that I am called upon to occupy, the scope and method of economic science, and its relation to other departments of what is vaguely called 'social science.' If the abstract and academic nature of the subject, together with my own deficiencies as an expositor, should render my remarks less interesting to the audience than they have a right to expect, I trust that they will give me what indulgence they can; but, above all, that they will not anticipate a corresponding remoteness from concrete fact in the discussions that are to follow. I see from the records of the Association that it has been the custom in this department—and it seems to me a good custom—to give to the annual addresses of the presidents the variety that naturally results when each speaker in turn applies himself unreservedly to that aspect of our complex and many-sided inquiry which his special studies and opportunities have best qualified him to treat; and as my own connection with economic science has been in the way of studying, criticising, and developing theories, rather than collecting and systematising facts, I have thought that I should at any rate have a greater chance of making a useful contribution to our discussions if I allowed myself to deal with the subject from the point of view that is most familiar to me.

I have the less scruple in adopting this course because I do not think that any who may listen to my remarks are likely to charge me with overrating the value of abstract reasoning on economic subjects, or regarding it as a substitute for an accurate and thorough investigation of facts instead of an indispensable instrument of such investigation. There is indeed a kind of political economy which flourishes in proud independence of facts, and undertakes to settle all practical problems of Governmental interference or private philanthropy by simple deduction from one or two general assumptions—of which the chief is the assumption of the universally beneficent and harmonious operation of self-interest well let alone. This kind of political economy is sometimes called 'orthodox,' though it has the characteristic unusual in orthodox doctrines of being repudiated by the majority of accredited teachers of the subject. But whether orthodox or not, I must be allowed to disclaim all connection with it; the more completely this survival of the *à priori* politics of the eighteenth century can be banished to the remotest available planet, the better it will be, in my opinion, for the progress of economic

science. Since, however, this kind of political economy is still somewhat current in the market-place, since the language of newspapers and public speakers still keeps up the impression that the professor of political economy is continually laying down laws which practical people are continually violating, it seems worth while to try to make clear the relation between the economic science which we are concerned to study and the principles of Governmental interference—or rather non-interference—which are thought to have been of late so persistently and in some cases so successfully outraged.

It must be admitted at once that there is considerable excuse for the popular misapprehension just mentioned; since for more than a century the general interest taken in the analysis of the phenomena of industry has been mainly due to the connection of this analysis with a political movement towards greater industrial freedom. No researches into the historical development of economic studies before Adam Smith can displace the great Scotchman from his position as the founder of modern political economy considered as an independent science, with a well-marked field of investigation and a definite and peculiar method of reasoning. And no doubt the element of Adam Smith's treatise which makes the most impression on the ordinary reader is his forcible advocacy of the 'system of natural liberty;' his exposition of the natural 'division of labour'—tending, if left alone, to become an international division of employments—as the main cause of the 'universal opulence' of 'well-governed' societies; and of the manner in which, in this distribution of employments, individual capitalists seeking their own advantage are led 'by an invisible hand' to 'prefer that employment of their capital which is most advantageous to society.'

At the same time Adam Smith was too cool and too shrewd an observer of facts to be carried, even by the force and persuasiveness of his own arguments, into a sweeping and unqualified assertion of the universality of the tendency that he describes. His advocacy of natural liberty in no way blinds him to the perpetual and complex opposition and conflict of economic interests involved in the unfettered efforts of individuals to get rich. He even goes the length of saying that 'the interest of the dealers in any particular branch of trade or manufacture is always in some respects different from, and even opposite to, that of the public.' To take a particular case, he is decidedly of opinion that the natural liberty of bankers to issue notes may reasonably be restrained by the laws of the freest Governments. He is quite aware, again, that the absence of Governmental interference does not necessarily imply a state of free competition, since the self-interest of individuals may lead them, on the contrary, to restrict competition by 'voluntary associations and agreements.' He does not doubt that Governments, central or local, may find various ways of employing wealth—of which elementary education is one of the most important—which will be even economically advantageous to society, though they could not be remuneratively undertaken by individual capitalists. In short, however fascinating the picture that Adam Smith presents to us of the continual and complex play of individual interests constituting and regulating the vast fabric of social industry, the summary conclusion drawn by some of his disciples that the social production of wealth will always be best promoted by leaving it altogether alone, that the only petition which industry should make to Government is the petition of Diogenes to Alexander that he would cease to stand between him and the sunshine, and that statesmen are therefore relieved of the necessity of examining carefully the grounds for industrial intervention in any particular case—this comfortable and labour-saving conclusion finds no support in a fair survey of Adam Smith's reasonings, though it has been no doubt encouraged by some of his phrases. To attribute to him a dogmatic theory of the natural right of the individual to absolute industrial independence—as some recent German writers are disposed to do[1]—is to construct the history of economic doctrines from one's inner consciousness.

It is true, as I have said, that among Adam Smith's disciples there were not a

[1] *E.g.*, v. Scheel, in Schönberg's *Handbuch der politischen Oekonomie*, p. 89, speaks of 'Die naturrechtliche Wirthschaftstheorie oder der Smithianismus.'

few who rushed to the sweeping generalisations that the master had avoided. In England, in particular, the influence of the more abstract and purely deductive method of Ricardo tended in this direction. It was natural, again, that in the heat of a political movement absolute and unqualified statements of principle should come into vogue, since the ease and simplicity with which they can be enunciated and apprehended makes them more effective instruments of popular agitation: hence it is not surprising to find the Anti-Corn-law petitions declaring the 'inalienable right of every man freely to exchange the result of his labour for the productions of other people,' to be 'one of the principles of eternal justice.' But under the more philosophic guidance of J. S. Mill, English political economy shook off all connexion with these antiquated metaphysics, and during the last generation has been generally united with a view of political principles more balanced, qualified, and empirical, and therefore more in harmony with the general tendencies of modern scientific thought.

If, indeed, *laisser-faire* were—as many suppose—the one main doctrine of modern political economy, there can be no doubt that the decisive step forward that founded the science ought to be attributed not to Adam Smith, but to his French la predecessors the 'Physiocrats.' It is to them—to Quesnay, De Gournay, De Rivière, Turgot—that the credit, whatever it may be, is due of having first proclaimed to the world with the utmost generality and without qualification that what a statesman had to do was not to make laws for industry, but merely to ascertain and protect from encroachment the simple, eternal, and immutable laws of nature, under which the production of wealth would regulate itself in the best possible way if men would abstain from meddling.

This doctrine formed one part of the impetuous movement of thought against the existing political order which characterised French speculation during the forty years that preceded the great Revolution. It was, we may say, the counterpart and complement of the doctrine of which Rousseau was the chief prophet. The sect of the Économistes and the disciples of Rousseau were agreed that the existing political system needed radical change; and in both there was a tendency to believe that an ideal political order could at once be constituted. At this point, however, their courses diverged: the school of Rousseau held that the essential thing was to alter the *structure* of government, and to keep legislation effectually in the hands of the sovereign people; the Économistes thought that the all-important point was to limit the *functions* of government, holding that the simple duty of maintaining the natural rights of the individual to liberty and property could be best performed by an absolute monarch. Both movements had much justification; both have had effects on the political and social life of Europe of which it is difficult to measure the extent; but both doctrines—attained, as they were, by a fallacious method—involved a large element of exaggeration, suitable to the ardent and sanguine period that brought them forth, but which gives them a curious air of absurdity when they are resuscitated and offered for the acceptance of our more sober, circumspect, and empirically-minded age. In the most civilised countries of Europe it is now a recognised and established safeguard against oppressive laws that an effective control over legislation is vested in the people at large: but no serious thinker would now maintain with Rousseau that the predominance of the will of the sovereign people has a necessary tendency to produce just legislation. Similarly, the doctrine of the Physiocrats has prevailed, in the main, as regards the internal conditions of national industry in modern civilised societies. The old hampering privileges, restraints, and prohibitions have been almost entirely swept away, to the great advantage of the community; but the absolute right of the individual to unlimited industrial freedom is now only maintained by a scanty and dwindling handful of doctrinaires, whom the progress of economic science has left stranded on the crude generalisations of an earlier period.

There will probably always be considerable disagreement in details among competent persons as to the propriety of Governmental interference in particular cases; but, apart from questions on which economic considerations must yield to political, moral, or social reasons of greater importance, it is an anachronism not

to recognise fully and frankly the existence of cases in which the industrial intervention of Government is desirable, even with a view to the most economical production of wealth. Hence, I conceive, the present business of economic theory in this department is to give a systematic and carefully-reasoned exposition of these cases, which, until the constitution of human nature and society are fundamentally altered, must always be regarded as exceptions to a general rule of non-interference. The statesman's decision on any particular case it does not belong to abstract theory to give; this can only be rationally arrived at after a careful examination of the special conditions of each practical problem at the particular time and place at which it presents itself. But abstract reasoning may supply a systematic view of the general occasions for Governmental interference, the different possible modes of such interference, and the general reasons for and against each of them, which may aid practical men both in finding and in estimating the decisive considerations in particular cases. Thus it may show, on the one hand, under what circumstances the inevitable drawbacks of Governmental management are likely to be least, and by what methods they may be minimised; and where, on the other hand, private enterprise is likely to fail in supplying a social need—as where an undertaking socially useful is likely for various reasons to be unremunerative to the undertakers—or where private interests are liable to be markedly opposed to those of the public, as is generally the case with businesses that tend to become monopolies.

It would be tedious now to dwell at length on these generalities; but there is one special exception to the triumph of the system of natural liberty in the civilised countries of Europe which has too much historical importance to be passed over without a word in this connection. As we are all aware, this triumph has only been decided as regards the *internal* conditions of industry and trade; the practice of imposing barriers on *international* exchange, with a view to the protection of native industry, still flourishes in the most advanced communities, and shows no immediate tendency to come to an end. It is not, I conceive, reasonable to attribute this result entirely, as some Free-traders are disposed to do, to the incapacity of mankind to understand elementary economic truths, and the interested efforts of a combination of producers to prey in a comfortable and legal way on the resources of the confiding consumers. I do not deny that both these causes have operated; but, in view of the evident ability and disinterestedness of many of the writers and statesmen who have supported the cause of Protection on the Continent or in the United States, I cannot find in them an adequate explanation of the phenomenon.

A part of the required explanation is, I think, suggested when we examine the arguments by which Free-trade was actually recommended to intelligent Englishmen at the time when England's policy was taking the decisive turn in this direction, and imagine their effect on the mind of an intelligent foreigner. Suppose, for instance, that the intelligent foreigner is studying the *Edinburgh Review* in 1841, when it came forward as a vigorous and decided advocate of Free-trade. In the January number he would find the cosmopolitan and abstract argument with which we are so familiar; he would learn how, under Free-trade, 'every country will exert itself in the way that is most beneficial in the production of wealth;' how labour and capital will be employed in each country to produce those things which the varieties of climate, situation, and soil enable it to produce with greater advantage than other countries, so that 'the greatest possible amount of industry will be kept constantly in action, and all commodities will exist in the greatest abundance.' But in the July number of the same organ he would find a recommendation of Free-trade from a national point of view, which, though more restricted in its scope, would appear to contain matter no less important for practical consideration. He would find that the immediate introduction of Free-trade was held to be essential in order to keep what remained of the manufacturing and commercial supremacy of England. He would learn that 'the early progress of any nation that attempts to rival us in manufactures must be slow;' for 'it has to contend with our great capital, our traditionary skill, our almost infinite division of labour, our long-established perseverance, energy, and enterprise,

our knowledge of markets, and with the habits of those who have been bred up to be our customers.' He would learn that there was 'no reason to believe that,' in the 'absence of disturbing causes,' we should ever lose our present command of the world's market; that we might have preserved our superiority for centuries; but that 'if these difficulties were once surmounted, this superiority—so far at least as respects the commodity in which we find ourselves undersold—would be gone for ever,' in consequence of 'the well-known law of manufacturing industry that, *ceteris paribus*, with every increase of the quantity produced, the relative cost of production is diminished.' It cannot be denied that a consideration of this law, and of the *vis inertiæ* here attributed to an established superiority in manufactures and commerce, supplies an important qualification of the general argument for Free-trade. For, along with the tendency of industry to go where it can be most economically carried on, we have also to recognise a tendency for it to stay and develop where it has been once planted; and the advantage of leaving this latter tendency undisturbed would naturally be less clear to the patriotic foreigner than to the patriotic Englishman. The proclamation of a free race for all, just when England had a start which she might probably keep 'for centuries,' would not seem to him a manifest realisation of eternal justice; to delay the race for a generation or two, and meanwhile to apply judiciously 'disturbing causes' in the form of protective duties, would seem likely to secure a fairer start for other nations, and ultimately, therefore, a better organisation of the world's industry even from a cosmopolitan point of view.

Nor would it seem to him a conclusive argument against this course that protective duties impose great present pecuniary sacrifices on the protecting nation; especially when he learnt, from an impartial English source, of the great sacrifices which private capitalists in England were in the habit of making to assist the tendency of free competition in their favour. He would find, for instance, in the Report of a Commission published in 1854,[1] an appeal to the working classes to consider 'the immense losses which their employers voluntarily incur in bad times, in order to destroy foreign competition, and to gain and keep possession of foreign markets.' Should the efforts of Trade-Unionists, urges the writer, be successful for any length of time, they would interfere with the 'great accumulations of capital which enable a few of the most wealthy capitalists to overwhelm all foreign competition in times of great depression,' and which thus constitute 'the great instruments of warfare against the competing capital of foreign countries.' If it was the view of shrewd English men of business that these great sacrifices of private wealth were needed, and were worth making, to maintain the industrial start once gained, the intelligent foreigner would naturally conclude that the other combatants in the industrial battle must be prepared to make corresponding sacrifices; that each nation must fight with its own weapons; and that where there were no great accumulations of capital in private hands, the instruments of warfare must be obtained by a general contribution.

I have given these considerations, not because I agree with the practical conclusion which they tend to support, but because I think that they require to be met by a line of argument different from that which English economists have usually adopted. I think it erroneous to maintain, on the ordinary economic grounds, that temporary Protection must always be detrimental to the protecting country, even if it were carried out by a perfectly wise and strong Government, able to resist all influences of sinister and sectarian interests, and to act solely for the good of the nation. The decisive argument against it is rather the political consideration that no actual Government is competent for this difficult and delicate task; that Protection, as actually applied under the play of political forces, is sure to foster many weak industries that have no chance of living without artificial support, and to hamper industries that might thrive independently, by the artificial dearness of some of their materials and instruments; so that it turns out a dangerous and clumsy, as well as a costly, instrument of industrial competition, and is

[1] See p. 20 of Report by Mr. H. S. Tremenheere, Commissioner appointed to inquire into the operation of Act 5 & 6 Vict. c. 99, and into the state of the population in the mining districts (Vol. XIX. of Parl. Papers for 1854).

not likely on the whole to bring the desired victory, though it may give a partial success here and there. And some such conclusion as this is, I think, now prevalent even among those German economists who are most decided in their rejection of the claims of *laisser-faire* to absolute and unqualified validity.

So far I have been speaking of the function of economic science in determining principles of Governmental intervention in matters of industry, because this is the function prominent in the popular view of political economy. But I need hardly say to the present audience that this is not the view that English economists generally have taken as to their primary business. Indeed, during the last generation our leading economists—even those who come nearest to the so-called 'orthodox' type—have gone even further than I should myself go in declaring that economic science had nothing to do with the doctrine of *laisser-faire*. No one (*e.g.*) has stated this more strongly than Cairnes, whom I select as a conspicuous and effective advocate of Free-trade. 'The maxim of *laissez-faire*,' he says, 'has no scientific basis whatever;' it is a 'mere handy rule of practice,' though 'a rule in the main sound.' According to this view, the 'laws' with which economic science is primarily concerned are the laws that determine economic quantities—the amount of the aggregate of wealth, its annual increase, the relative values of its different elements, and the shares of the economic classes that have combined to produce it—as they would be apart from special Governmental interference; and not the rules for deciding when and how far such interference is justifiable.

And it is the additional light that Adam Smith threw on the general determination of such economic quantities—and not his advocacy of natural liberty—which in the view of economists constitutes his chief claim to his place in the historical development of economic science. And I may observe that, from this point of view, the important predecessors of Adam Smith are not the Physiocrats only, but even more Cantillon, who wrote a generation before, to whom Jevons drew attention some years ago in a remarkable essay; nor shall we overlook his English predecessors of a still earlier age, such as Petty and Locke—the former of whom has a special interest for us as a pioneer in each of the two lines of investigation of which we here maintain the union, since he was the first in England to combine a serious effort to establish the general relations of economic quantities by abstract reasoning and analysis with patient endeavours to ascertain particular economic facts by statistical inquiries. When we trace the gradual evolution of the modern economic view as to the manner in which the play of individual self-interests tends to determine prices and shares—from the rude beginnings of Petty and Locke, through the more systematic and penetrating theory of Cantillon, the fuller analysis and exposition of Adam Smith, and the closer reasoning of Ricardo, down to the important rectifications and additions of Jevons—we see clearly that the progress of the theory has no necessary connection with any doctrine as to the limits of the industrial intervention of Government.

And it is to be observed that neither Adam Smith nor the predecessors to whom I have referred had any design of maintaining that the distribution which they were endeavouring to analyse satisfied either the claims of ideal equity by giving each individual his deserts, or the claims of expediency by giving him what was most conducive to general happiness. Nor, since Adam Smith, has any leading English economist maintained the former of these propositions; and so far as the school of Ricardo may have seemed to maintain the latter—so far as they certainly have taught that direct Governmental interference with distribution was undesirable—it has not been from any prevalence among them of the shallow optimism of Bastiat and his followers. It is pessimism rather than optimism which is to be laid to their charge; not a disposition to underrate or ignore the hardships that the 'natural' rate of wages might entail; but a conviction that, however bad things might be naturally, the direct interference of Government could only make them worse. I am not arguing that they did not go too far in this view; I am now chiefly desirous to remove a profound and widespread misunderstanding as to the general aim and drift of their investigations, which I find in certain German and other Continental critics of English political economy, and, I may add, in certain English critics who repeat the foreign objections. Such critics either fail to

see, or continually forget, that the English economist, in giving an explanation of the manner in which prices, wages, profits, &c., are determined, is not attempting to justify the result; he is not trying to show that in getting the market price of his services the labourer, capitalist, or landlord gets what he deserves. Thus when Senior called interest the 'reward of abstinence,' he did not mean to imply that it was normally proportioned to the capitalist's merit in abstaining, but merely that capital is increased by individuals saving instead of spending, and that they require the inducement given by the actual rate of interest to save to the extent to which they actually are saving. Whether any other rate of interest would be *juster* is a question of ideal politics to which the English economist has usually nothing to say so long as it is stated in this abstract form; it is only when the political idealist descends to practice, and proposes a scheme for realising his conception of justice, that it comes within the province of economic science to discuss the probable effects of this scheme on production and distribution. But it is not with such far-reaching proposals of change that the English economist is mainly concerned; his primary business is to ascertain the causes which determine actual prices of products and services.

Hence, when the most recent German school of economists—variously known as the 'historical,' 'ethical,' or 'social' school—claims to have moralised political economy by throwing over the assumption of egoism, which they regard as characteristic of 'Smithianismus,' they usually appear to the English economist to confound what is with what ought to be. The assumption that egoism ought to be universal—that the universal prevalence of self-interest leads necessarily to the best possible economic order—has never been made by leading English writers; and it is an assumption with which they generally conceive themselves in no way concerned—in that part, at least, of the science which deals with distribution. It is the actual prevalence of self-interest in ordinary exchanges of products and services which constitutes their fundamental assumption.

But I admit that this reply does not end the controversy. The critic may rejoin that, if egoism is not what it ought to be, the tranquil way in which the economist treats it as universally predominant is objectionable, as tending to give dangerous encouragement to the baser side of human nature. And, secondly, he may deny that self-interest actually has any such predominance as English economists assume; hence, he may argue, their fundamental assumption must lead to serious errors in the analysis and forecast of actual facts.

The first of these points I should concede to some extent. If we regarded it as blameworthy that a man should, under ordinary circumstances, try to get the highest price for any commodity he sells, and give the lowest for what he buys, then, though the analysis of economic facts, as they exist in the present selfish and wicked world, might still be conducted on the present method, I certainly think its results ought to be—and would be—expounded in a different tone. I should say, therefore, that our economists generally do not hold to be censurable, in a broad and general way, the self-regard which they assume as normal. I conceive, however, that this view is commonly held with the following important qualifications.

Firstly, it is not implied that the right of free exchange ought not to be legally limited in respect of certain special commodities. Thus, when it is urged by statesmen or philanthropists that the sale of opium, or brandy, or lottery-tickets, or children's labour ought to be prohibited or placed under certain restrictions, the political economist, as such, is not to be regarded as holding a brief on the other side—at most he only throws the *onus probandi* on those who advocate interference, adding perhaps a warning that the consequences of their measure may possibly be different from what they anticipate, owing to the play of ordinary self-regard working under the new conditions that they aim at imposing.

Secondly, it is not implied that similar limitations may not be effectively imposed by the force of moral opinion. It has, indeed, to be pointed out that morality, like law, may produce effects other than what are designed—*e.g.* that the discredit attaching to usury may cause the unhappy debtor to pay more instead of less for his inevitable loan, since the usurer has to be compensated for the social drawbacks

of his despised employment. But it does not follow that there are no cases in which this disadvantage has to be faced as the least of two evils.

Thirdly, the economist does not assume that his economic man is *always* buying in the cheapest and selling in the dearest market, and never rendering services to his fellow-creatures on any other terms. He does not lay down that the economic distribution which it is his business to analyse will not be supplemented to an indefinite extent by a distribution prompted by other motives:—indeed, it should be noted that the ordinary economic man is always understood to be busily providing for a wife and children; so that his dominant motive to industry is rather domestic interest than self-interest, strictly so-called. And it has never been supposed that outside his private business—or even in connection with it if occasion arises—a man will not spend labour and money for public objects, and give freely gratuitous services to friends, benefactors, and persons in special need or distress.

The political economists, it is true, have often felt called upon to criticise the proceedings of philanthropists; but those who have assumed in enunciating these criticisms a grave air of giving the results of abstruse scientific reasoning are partly to blame, I think, for having drawn on political economy a kind of odium which ought to have been thrown on the broader back of plain common sense. We may say, indeed, with special force of a great part of economic science what Huxley has said of science generally—that it is only 'organised common sense.' But it needs little organisation to show that the motives to industry and thrift are impaired by the indiscriminate relief of the idle and improvident; that you help men best by encouraging them to help themselves, by widening the opportunities for the display of energetic activity and enterprise, and diffusing the knowledge that will save it from being wasted, rather than by diminishing the inducements that stimulate it. To apprehend the truth of propositions like these, a man need not even have read a shilling handbook; and yet these commonplaces constitute the greater part of the 'hard-hearted economist's' criticism of sentimental philanthropy. If, indeed, the economist has gone on to say that therefore no efforts ought to be made to relieve distress, and raise those who have temporarily stumbled in the struggle for existence, or if he has prophesied failure to all larger attempts on the part of philanthropists to improve the condition of the classes at the base of the industrial pyramid—if, I say, an individual economist has here and there been found lecturing and prognosticating in this sweeping manner, he has only exemplified the common human tendency to dogmatise beyond the limits of his knowledge; and I trust the blame will not be laid on the science whose exacter methods he has deserted or misapplied.

The important question of method, then, at issue between the English economists and their German critics is not whether the play of the ordinary motives of self-interest ought to be limited and supplemented by the operation of other motives; but whether these other motives actually do, or can reasonably be expected to, operate in such a way as to destroy the general applicability of the method of economic analysis which assumes that each party to any free exchange will prefer his own interest to that of the other party. And in speaking of the German historical school as antagonists on this question, I ought to say that I refer only to what I may call their more aggressive left wing. With the more moderate claims of the historical method as set forth by the distinguished leader of the school, William Roscher, the English economists who maintain the tradition of Adam Smith and Ricardo have no sort of quarrel; and Roscher expressly disclaims any quarrel with them. He has sought, as he says, 'gratefully to avail himself' of the results of Ricardian analysis, and we can no less gratefully profit by the abundant historical researches that he has led and stimulated. It is no doubt true that our older economists often had an insufficient appreciation of the historical variations in economic conditions; and, in particular, did not adequately recognise the greater extent to which competition was limited or repressed by law or custom in states of society economically less advanced than our own. But for a generation there has been no serious dispute about this; nor has there ever been any fundamental disagreement between Ricardians and Roscherians as to the right method of studying the history of economic facts. The most deductive English economist has

never gone so far as to maintain that this can be constructed *à priori*, any more than any other history; and if a generation ago he was sometimes wont to dogmatise with insufficient information as to the causes of industrial changes and the economic effects of political measures in other ages and countries, he has grown wiser, like other persons, through the great development of historical study—and of what I may call the common historic sense of educated persons—which has taken place in the interval. Indeed, I think the danger now is rather that we should go into the opposite extreme, and not give sufficient attention to the more latent and complicated but very effective manner in which competition is found operating even in states of society where the barriers of custom are strongest.

But further, even as regards the present condition of industry in the more advanced countries, to which the theory of modern economic science primarily relates, there is, I conceive, no dispute as to the need of what is called a 'realistic' or 'inductive' method—*i.e.* as to the need of accurately ascertaining particular facts when we are inquiring into the particular causes of particular values, or of the shares of particular economic classes at any given place and time. All that the deductive reasonings of English economists supply is a method of analysing the phenomena and a statement of the general causes that govern them, and of the manner of their operation. In this analysis, no doubt, the assumption is fundamental that the individuals concerned in the actual determination of the economic quantities resulting from free exchange will aim, *ceteris paribus*, at getting the most they can for what they sell and giving the least they can for what they buy. And when we find the legitimacy of this assumption, and the scientific value of the analysis based upon it, broadly assailed by Hildebrand,[1] Knies,[2] and others, we are no doubt seriously concerned to meet their criticism.

For my own part, I can only say that, having searched their works with the interest and respect which are due to the indefatigable research and the scientific fertility of the German intellect, I am quite unable to discover what other scientific treatment of the general theory of distribution and exchange they propose to substitute for the treatment which they sweepingly criticise. I cannot perceive that their higher view of man as a moral, sympathetic, public-spirited being, habitually rising above the sordid huckstering considerations by which English economists assume him to be governed, has any material effect on their theory of the determination of economic quantities when it comes to be actually worked out. When Knies,[3] for instance, is discussing the nature and functions of capital, money, and credit, or when he is arguing with more subtlety than success against the Ricardian doctrine of rent, we find that the capitalists and landlords, the lenders and borrowers, whose operations are contemplated, exhibit throughout the familiar features of the old economic man. So, again, when, in the Encyclopædia of Political Economy[4] recently published by this school, we examine the definitions of fundamental notions, or the explanation of prices, or the theory of distribution, we meet, indeed, with some interesting variations on the old doctrines, but we find everywhere the old economic motives assumed and the old method unhesitatingly applied. The proof of the pudding, as the proverb says, is in the eating; but our historical friends make no attempt to set before us the new economic pudding which their large phrases seemed to promise. It is only the old pudding with a little more ethical sauce and a little more garnish of historical illustrations.

In saying this I should be sorry to seem to underrate the debt that economic science owes to the labours of the school now dominant in Germany. Much of the positive work that they have produced is in its way excellent; even their criticism of the older method has been, in my opinion, most useful; and if I complain that they have by no means done what they announced, with some flourish of trumpets,

[1] See two papers on 'Die gegenwärtige Aufgabe der Wissenschaft der politischen Oekonomie,' in the first volume (1863) of Hildebrand's *Jahrbuch für National-Oekonomie u. Statistik*, p. 5ff. and p. 137ff.: especially his criticism of J. S. Mill (p. 23), quoted with approval by Schönberg in the introduction to his *Handbuch*.

[2] See his *Politische Oekonomie vom geschichtlichen Standpunkte*, iii. § 3.

[3] See his *Geld und Credit*—in particular, *Credit*, pt. ii. ch. xii. § 2.

[4] See Schönberg's *Handbuch*, iv. v. and xi.

that they were going to do, it is chiefly because their exaggerated phrases have led critics of a looser sort to misunderstand and misrepresent the recent progress and actual condition of economic thought. I fully recognise that the elaborate and careful study of economic facts in all departments, which the historical school has encouraged and carried out, is an indispensable aid to the due development of general economic theory. In all abstract economic reasoning which aims at quantitative precision, there is necessarily a hypothetical element; the facts to which the reasonings relate are not contemplated in their actual complexity, but in an artificially simplified form; if, therefore, the reasoning is not accompanied and checked by a careful study of facts, the required simplification may easily go too far or be inappropriate in kind, so that the hypothetical element of the reasoning is increased to an extent which prevents the result from having any practical value. And this danger is enhanced by the great, though generally gradual, changes in economic facts which accompany or constitute industrial development. Thus, for instance, a theoretical investigation of the purchasing power of money, which assumes for simplicity that coin and bank-notes form the sole medium of exchange, might easily lead to serious practical errors in the existing condition of industry; and a theory of capital which ignores the great and growing preponderance of auxiliary over remuneratory capital is liable to be similarly delusive. The general study of economic history is important as calling attention to this source of error: but for effective protection against it we must look to that patient and systematic development of statistical enquiry, which it is one of our main functions here to watch and to foster.

I must observe, however, that the historical economists are apt to insist too one-sidedly on the progress in economic theory attained by studying the industrial organisation of society in different stages of its development; they do not sufficiently recognise that other kind of progress which consists in conceiving more clearly, accurately, and consistently, the fundamental facts that remain without material change. But this latter kind of progress is very palpable to one who traces back the history of economic doctrines. Indeed, if our active controversy on principles and method has led anyone to think that political economists are always wrangling, and never establishing anything, he may easily correct this impression by turning to the older writers, and noting the confusions they make on points that are now clear to all instructed persons, and the inferences they unhesitatingly draw, which all would now admit to be in whole or in part erroneous. And by the 'older writers' I do not mean merely those who lived before Adam Smith: what I have just said is no less true of the 'Wealth of Nations' and its most distinguished successors. A tiro can now see the fallacy of Adam Smith's statement, that 'labour never varying in its own value' is a 'universal' and 'accurate standard of the exchangeable value of all commodities at all times and places'; the staunchest Ricardian would refuse to follow his master in maintaining that a tax on corn would cause labourers 'no other inconvenience than that which they would suffer from any other mode of taxation'; the most faithful disciple of J. S. Mill would not fall into the confusion between 'interest' and 'profit' which seriously impairs the value of important parts of his discussions. Much progress, I doubt not, still remains to be made, by steadily continuing that labour of reflective analysis through which our conception of fundamental economic facts has grown continually fuller and more exact; but no one who examines impartially the writings of our most eminent predecessors can ignore the progress that has already been made.

I now pass to consider another old charge against political economists, which has been recently revived: the charge of confining their attention too much to the special group of phenomena with which they are primarily concerned, and neglecting the relations of these to other social facts. There have, no doubt, been writers—Senior is, perhaps, the most important—in whom such neglect was deliberate and systematic; but their peculiar view of economic method has long ceased to have much influence on current thought; and I hardly think that political economists are now more open to the charge of systematic narrowness than any other set of students who do not 'take all knowledge for their province,' but accept the limitations which the present state of research imposes as the inevitable condi-

tion of thorough work in any department. And so far as the charge hits a real defect, I doubt whether vague generalities about the 'consensus of the different functions of the social organism,' and the impossibility of 'isolating the study of one organ from that of the rest,' will be found of much practical use in correcting the defect; since the relations of other social phenomena to those which primarily concern the economist vary indefinitely in closeness and importance; so that the question how far it is needful to investigate them is one which has to be answered very differently in relation to different economic enquiries. Thus, in considering generally the first subject of Adam Smith's investigation—'the causes of the improvement in the productive powers of labour'—the importance of a healthy condition of social morality must not be overlooked; but it is not therefore the economist's duty to study in detail the doctrine or discipline of the different Christian churches: while any reference he may make to the history of the Fine Arts will obviously be still more remote and brief. If, however, we are considering historically the causes that have affected the interest of capital, the views of Christian theologians with regard to usury will require careful attention; if, again, we are investigating the share taken by a particular community in the international organisation of industry, the higher average of artistic sensibility among its members may be a consideration deserving of notice—as in the case of France.

Or again, we may illustrate the different degrees in which economic science is connected with different departments of social fact by comparing the chief classes of statistics with which this Section has concerned itself. Some of the most important of these—such as the statistics of taxation, trade, railways, land-tenure and the like, and a great part of the statistics of population—obviously supply the indispensable premisses of much of the economist's reasoning, so far as it aims at being precise and particular, and the indispensable verification of many of his conclusions. In other cases again, as, for instance, the great departments of sanitary and educational statistics, the interest of the economist is more general and limited: for though both sanitation and education have important bearings on the productiveness of national labour, the details of the organisation for promoting either end lie in the main beyond the scope of his investigation; while he has manifestly still less to do with criminal statistics, military and naval statistics, and several other species of social facts which governmental or private agencies now enable us to ascertain with approximate quantitative exactness.

At this point, however, our critics will probably say that it is not so much a knowledge of the separate relations of different groups of social phenomena that the political economist lacks, but rather a true conception of the social organism as a whole, and of the fundamental laws of its development; he does not recognise that his study can only be legitimately or profitably pursued as a duly subordinated branch of the general science of sociology. This view was strongly urged by Mr. Ingram in his presidential address to this Section seven years ago in Dublin [1]; and it was enforced by pointing contemptuously to the limited function which well-instructed economists at the present day are careful to allot to their science in the settlement of practical questions. When we explain, with Cairnes, that political economy furnishes certain data that go towards the formation of a sound opinion on such questions, but does not undertake to pronounce a final judgment on them, we are told that this 'systematic indifferentism amounts to an entire paralysis of political economy as a social power'; and that the time has come for it to make way for, or be absorbed into, the 'scientific sociology' which is now in the field, and certainly seems ready to offer statesmen the dogmatic, comprehensive, and complete practical guidance which mere economic science confesses itself inadequate to supply.

It appears to me that Mr. Ingram and his friends somewhat mistake the point that they have to prove. It is not necessary to show that if we could ascertain from the past history of human society the fundamental laws of social evolution as a whole, so that we could accurately forecast the main features of the future state

[1] It has been recently expressed again, with no less emphasis, in Mr. Ingram's article on 'Political Economy,' in the nineteenth volume of the *Encyclopædia Britannica*.

with which our present social world is pregnant—it is not needful, I say, to show that the science which gave this foresight would be of the highest value to a statesman, and would absorb or dominate our present political economy. What has to be proved is that this supremely important knowledge is within our grasp; that the sociology which professes this prevision is really an established science. To deny this may perhaps seem presumptuous, in view of the voluminous works that we possess on the subject, which it would be quite out of place for me to attempt to criticise methodically on the present occasion. Fortunately, however, such methodical criticism is not required to justify my negative conclusion: since there are two simple tests of the real establishment of a science—emphatically recognised by Comte in his discussion of this very subject—which can be quickly and decisively applied to the claims of existing sociology. These tests may be characterised as (1) Consensus or Continuity and (2) Prevision. The former I will explain in Comte's own words:—'When we find that recent works, instead of being the result and development of what has gone before, have a character as personal as that of their authors, and bring the most fundamental ideas into question'—then, says Comte, we may be sure we are not dealing with any doctrine deserving the name of positive science. Now, if we compare the most elaborate and ambitious treatises on sociology, of which there happens to be one in each of the three leading scientific languages—Comte's 'Politique Positive,' Spencer's 'Sociology,' and Schäffle's 'Bau und Leben des socialen Körpers,'—we see at once that they exhibit the most complete and conspicuous absence of agreement or continuity in their treatment of the fundamental questions of social evolution.

Take, for example, the question of the future of religion. No thoughtful person can overlook the importance of religion as an element of man's social existence; nor do the sociologists to whom I have referred fail to recognise it. But if we inquire after the characteristics of the religion of which their science leads them to foresee the coming prevalence, they give with nearly equal confidence answers as divergent as can be conceived. Schäffle cannot comprehend that the place of the great Christian Churches can be taken by anything but a purified form of Christianity; Spencer contemplates complacently the reduction of religious thought and sentiment to a perfectly indefinite consciousness of an Unknowable and the emotion that accompanies this peculiar intellectual exercise; while Comte has no doubt that the whole history of religion—which, as he says, 'should resume the entire history of human development'—has been leading up to the worship of the Great Being, Humanity, personified domestically for each normal male individual by his nearest female relatives. It would certainly seem that the science which allows these discrepancies in its chief expositors must be still in its infancy. And when we go on to ask how these divergent forecasts of the future are scientifically deduced from the study of the past evolution of mankind, we are irresistibly reminded of the old epigram as to the relation of certain theological controversialists to the Bible:

Hic liber est in quo quærit sua dogmata quisque,
Invenit et pariter dogmata quisque sua.

I do not doubt that our sociologists are sincere in setting before us their conception of the coming social state as the last term of a series of which the law has been discovered by patient historical study; but when we look closely into their work it becomes only too evident that each philosopher has constructed on the basis of personal feeling and experience his ideal future in which our present social deficiencies are to be remedied and that the process by which history is arranged in steps pointing towards his Utopia bears not the faintest resemblance to a scientific demonstration.

This is equally evident when we turn from religion to industry, and examine the forecasts of industrial development offered to the statesman in the name of scientific sociology as a substitute for the discarded calculations of the mere economist. With equal confidence, history is represented as leading up, now to the naïve and unqualified individualism of Spencer, now to the carefully guarded and elaborated socialism of Schäffle, now to Comte's dream of securing seven-roomed houses for all working men—with other comforts to correspond—solely by the im-

pressive moral precepts of his philosophic priests. Guidance, truly, is here enough and to spare; but how is the bewildered statesman to select his guidance when his sociological doctors exhibit this portentous disagreement?

Nor is it only that they adopt diametrically opposite conclusions: we find that each adopts his conclusion with the most serene and complete indifference to the line of historical reasoning on which his brother sociologist relies. Schäffle, *e.g.*, appears not to have the least inkling of the array of facts which have convinced Spencer that the recent movement towards increased industrial intervention of government in Germany and England is causally connected with the contemporaneous recrudescence of 'militancy' in the two countries. And similarly, when Spencer explains how, under a régime of private property and free contract, there is necessarily a 'correct apportioning of reward to merit,' so that each worker 'obtains as much benefit as his efforts are equivalent to—no more and no less,' he exhibits a total ignorance of the crushing refutation which, according to Schäffle, this individualistic fallacy has received at the hands of socialism. The tendency of free competition to annihilate itself, and give birth to monopolies exercised against the common interest for the private advantage of the monopolists; the crushing inequality of industrial opportunities, which the legal equality and freedom of modern society has no apparent tendency to correct; the impossibility of remunerating by private sale of commodities some most important services to the community; the unforeseen fluctuations of supply and demand which a world-wide organisation of industry brings with it, liable to inflict, to an increasing extent, undeserved economic ruin upon large groups of industrious workers; the waste incident to the competitive system, through profuse and ostentatious advertisements, needless multiplication of middle-men, inevitable non-employment, or half-employment, of many competitors; the demoralisation, worse than waste, due to the reckless or fradulent promotion of joint-stock companies, and to the gambling rife in the great markets, and tending more and more to spread over the whole area of production —such points as these are unnoticed in the broad view which our English sociologist takes of the modern industrial society gradually emancipating itself from militancy: it never enters his head that they can have anything to do with causing the movement towards socialism to which his German *confrère* has yielded.[1]

However, whether Spencer or Schäffle is a true prophet—whether the decay of war will bring us to a more complete individualism, or whether the increasing scale of the organisation of industry and its increasingly marked deficiencies are preparing the way for socialism—cannot certainly be known before a date more or less distant. But as Comte's sociological treatise was written a generation ago, we are fortunately able to bring his very definite predictions and counsels to the test of accomplished facts. In 1854 he announced that the transition which was to terminate the Western Revolution would be organised from Paris, the 'religious metropolis of regenerate humanity,' where an 'irreversible dictatorship' had just been established, within the space of a generation. In the initial phase of the transition, which ought to last about seven years, perfect freedom of the press would 'rapidly extinguish journalism,' owing to the 'inability of the journal to compete with the placard.' By a 'judicious use of placards, with a few occasional pamphlets,' Positivism would regenerate public opinion. The budget of the clergy, the University of France, the Academy of Sciences must be suppressed, and the proximate abolition of copyright announced. By these moderate measures Louis Napoleon's irreversible dictatorship might be 'perfected and consolidated,' so that the dictator might assume complete legislative power, reducing the Representative Assembly—which would sit once in three years—to the purely financial function of voting the budget. In the second phase of the transition, which should last about five years, the 'dictatorial government now unquestionably progressive,' would suppress the French army, substituting a constabulary of 80,000 gendarmes. This would suffice to maintain order, internal and external, as the oppressive

[1] See Schäffle's 'Kritik der kapitalistischen Epoche,' in *Bau und Leben des socialen Körpers*, vol. iii. pp. 419–457.

military establishments of neighbouring states would everywhere fall as soon as France had put down her army. The dictator would then break up France into seventeen separate intendancies as a step towards the ultimate Positive régime, under which the peoples of Western Europe are to be distributed into seventy republics, comprising about 300,000 families each. The third and last phase of the transition, which should occupy about twenty-one years, might be expected to be opened by the voluntary abdication of the dictator in favour of a triumvirate, consisting probably of a banker to manage foreign affairs, an 'agricultural patrician' as minister of the interior, and a working man to take charge of the finances. Their names would be suggested by the High Priest of Humanity—indeed, Comte tells us that he had been 'working for several years at the choice of persons,' in order to be ready for this momentous nomination: for the immense influence which Positivist doctrine ought to have gained by this time would enable the political direction of France to be placed completely in the hands of Positivists. This triumvirate would transform the seventeen intendancies into separate republics: the *bourgeoisie* would then be gradually 'eliminated' by the extinction of *littérateurs*, lawyers, and small capitalists, so that society would pass easily into the final régime.[1]

I need not go on to this final régime: I have already given you more than enough of these extravagances; but it seemed important to show how completely the delusive belief that he had constructed the science of sociology could transform a philosopher of remarkable power and insight into the likeness of a crazy charlatan. I trust that our Association will take no step calculated to foster delusions of this kind. There is no reason to despair of the progress of general sociology; but I do not think that its development can be really promoted by shutting our eyes to its present very rudimentary condition. When the general science of society has solved the problems which it has as yet only managed to define more or less clearly—when for positive knowledge it can offer us something better than a mixture of vague and variously applied physiological analogies, imperfectly verified historical generalisations, and unwarranted political predictions—when it has succeeded in establishing on the basis of a really scientific induction its forecasts of social evolution—it will not require any formal admission to the discussions of this Section; its existence will be irresistibly felt throughout the range of the more special inquiries into different departments of social fact to which we have hitherto restricted ourselves. It is our business in the meantime to carry on our more limited and empirical studies of society in as scientific a manner as possible. Of the method of statistical investigation I have not presumed to speak, as I have not myself done any work of this kind, but have merely availed myself gratefully of the labours of others. But, even so, it has been impossible for me not to learn that to do this work in its entirety, as it ought to be done, requires scientific faculties of a high order. For duly discerning the various sources of error that impede the quantitative ascertainment of social facts, eliminating such error as far as possible, and allowing for it where it cannot be eliminated—still more for duly analysing differences and fluctuations in the social quantities ascertained, and distinguishing causal from accidental variations and correspondences—there is needed not only industry, patience, accuracy, but a perpetually alert and circumspect activity of the reasoning powers; nor is the statistician completely equipped for his task of discovering empirical laws unless he can effectively use the assistance of an abstract and difficult calculus of probabilities. It is satisfactory to think that there is every prospect of statistical investigations being carried on, in an increasingly comprehensive and systematic manner, throughout an ever widening range of civilised countries. The results of this development cannot fail to be important from the statesman's no less than the theorist's point of view: for though the statistician, as such, does not profess to guide public opinion on political questions, there can be no doubt—as Mr. Giffen has recently pointed out—that the knowledge attained by him tends to exercise on the general discussion of such questions an influence, on the whole, no less salutary than profound.

[1] These details are taken from Comte's *Système de Politique Positive*, vol. iv. chap. v.

2. *On the alleged Depression of Trade. By* Professor LEONE LEVI, *F.S.S.*

The paper criticised numerous essays upon which the author had been recently asked to adjudicate. The value of these essays did not consist in the discovery of any new method for the prevention or remedy of such depression—they did not expect that—but rather in their presenting a well-digested survey of the circumstances which preceded and the causes which produced the depression. There was nothing new, indeed, in the occurrence of even a somewhat protracted depression of trade. Some have gone so far as to detect a connection between the solar surface and certain terrestrial phenomena, as between sunspots and the price of wheat. The causes of the present depression were variously stated by the different essayists. Among the causes mentioned are—the diminished production and consequent appreciation of gold; the heavy losses in agriculture consequent on several successive bad harvests, accompanied by competition of large foreign imports brought to this country at exceedingly low rates of freight; over-production in manufacture, shipping, iron, coal, in fact, in production of every kind, the effect of improved plant and machinery, as well as of larger amount and greater concentration of capital; heavy losses of national resources caused by numerous destructive wars, and the large war expenditure yearly incurred by the principal countries of Europe; extensive speculative investments utterly disappointing in their results; an excessive expenditure in alcoholic beverages and the improvidence of the working classes; the restrictive tariffs in many States which intercept the free course of commerce and condemn nations to suffer, either from the exclusion of necessary or useful commodities or from excessive monopoly prices; the cessation of great discoveries, and the revolution produced by the greater speed in communication. Among the remedies suggested for commerce and manufacture are—the introduction of better machinery and improved processes in manufacture; the opening of new channels of trade, and greater economy both in production and distribution; and for agriculture, a cheaper and safer system for the transfer of land, as well as greater stability of tenure. Only one essay out of fifty-eight was found to advocate fair-trade, and to bring forward reasons against the maintenance of our free-trade policy. A comparison had been made of the amount of trade in 1873 and 1883; but 1873 was an exceptional year. For a sound view of the condition of trade a longer period was necessary. If they divided the last twenty years into four quinquennial periods, they found that, measured per head of the population, and comparing 1865–69 with 1880-85, the imports show an increase of 19·57 per cent., and the exports of British produce and manufacture show an increase of 11·76 per cent., while there was an increase in the total trade at the rate of 19·64 per cent. The total trade of the United Kingdom, which in 1865–69 averaged 516,000,000*l.*, rose in 1880–84 to 707,000,000*l.* But, while the declared value of imports and exports is determined by the prices, the consuming power of the people was best seen by the quantities received or sent out. The shipping returns showed that, whilst in 1865–69 the tonnage of British and foreign vessels cleared at ports with cargoes only to foreign countries averaged 14,614,000 tons, in 1880–84 it averaged 27,673,000 tons. Whilst the population of the principal countries increased at the rate of 10 per cent. in ten years, our exports in value increased at the rate of upwards of 40 per cent., and in quantity at a still greater rate in twenty years. The best reason for low prices would be found in the increasing production of different articles, the improved facilities of communication, lower freight, &c. There are still a few, he trusted only a very few, who lamented our increasing dependence on foreign countries for the necessaries of life, and who contended that the excessive balance of imports over exports indicated an enormous indebtedness to foreign countries or an absolute loss in our exchanges. In their opinion, with a view to the greater employment of the labouring classes at home, and as a matter of simple fairness to the people of this country, we should prohibit or restrict the imports of manufactured and even semi-manufactured articles, including, for instance, wheat-flour. Nay, more, what they advocate is to do unto others what they do unto us, meet prohibition with prohibition, high duties with high duties, and bounties with countervailing duties. It should be re-

membered, however, that the increasing imports of articles of food are on the one hand the consequence of the improved condition of the people, which enables them to eat and drink more than they were able to do in former years, and on the other hand the result of natural conditions which determine and limit the productiveness of the soil in the United Kingdom—a fact which we cannot remedy, and which we can only meet by the importation of foreign produce. We would commit the greatest possible error were we to attempt to benefit the working classes by the restriction of the imports and by the reduction of the amount of foreign trade: any restraint of that character having the effect of benefiting the few at the expense of the many. Doubtless we must lament the prevalence of erroneous economic principles in several countries; financial exigencies, and more especially the influence of interested parties in the Government and in the Legislature, have retarded the practical adoption of principles admitted to be sound and unquestionable. But no political economist anywhere has ever spoken a word in favour of either restrictive tariffs, bounties, or prohibitions. The general condition of trade is certainly considerably altered, and is much more precarious than it was fifteen or twenty years ago. First of all, an increasing competition exists at home and abroad, not only among producers, but among distributors. At this moment Chinese and Japanese merchants compete with British merchants in the trade of the East, just as French and German manufacturers are striving to wrest from the British manufacturers a share in the supply of the textile and other manufactures. Nor have a few capitalists any longer a monopoly of trade. By the extension of joint-stock companies with limited liability, hundreds of millions find their way into trade and public works, and these companies being content with realising a small percentage of profits, private merchants must consent to work on equal terms. By the greater vigilance of workmen, manufacturers have no longer in their power to maintain wages at as low a rate as possible. They are made to divide with the workmen in the shape of higher wages a full portion of their profits. And the advantages which leading merchants once possessed from their extensive agencies are neutralised or lost by the promptitude with which everything is communicated to the world through the press, whilst electricity and steam have by their speedy or instantaneous movement greatly narrowed the field of speculation. Monometallism, or Bimetallism, has nothing to do with the depression of trade. Money is plentiful. What is wanted are a greater diffusion of comforts, and more confidence in political and social tranquillity. Altogether ill-founded are the complaints made against free-trade. Deeper causes than any changes in the commercial policy of this or of any country have produced the depression of trade so much complained of. If the Royal Commission lately appointed on the depression of trade, or any members of the same, are in any expectation that the facts which may be presented to them justify either the reimposition of the Corn Laws, or the introduction of differential duties in favour of the British Colonies and against foreign countries, or a prohibitive or restrictive tariff of imports, they will be grievously disappointed. I do not object to an inquiry. It will put an end to much idle talk. It will show on what foundation of sand fair-traders and protectionists are relying. The verdict of the nation has long been pronounced, and the Royal Commission summoned to, if possible, reverse the same will, like Balak of old, not only reject the appeal, but confirm it as irrevocable. Royal Commissions cannot improve trade. What we require is to open and not to shut the avenues of wealth. We are all deeply concerned in its increase all over the world. All nations depend on the abundance of their harvest from year to year. Let us pray that their garners may be full, affording all manner of store. Commerce will ever be the landmark of peace. Let us rebuke the thoughtless, the suicidal mania for a warlike policy; let us put a check to the ruinous maintenance of enormous armies. Britain need not fear competition, and there is no reason why her productions should be inferior to those of any other nation in solidity, taste, and economy. She possesses a cheap and abundant supply of coal and iron—she has a climate most conducive to continuous labour, and plenty of workers fully apt, would that they had always the will for their work. Wages are not higher here than in other countries, when we take into account the relative power exerted on matter. Nor

are the limited hours of labour a disadvantage, for labour saved is not lost. Britain has more capital than any other country, and nowhere the value of money is lower than in the United Kingdom. She has almost a monopoly of the carrying trade of the world, and she has the goodwill of a large and well-established custom. By all means let other nations advance in wealth and industry. There is room for all. Let us only trust for better times, and we may be quite sure that any rays of sunshine which may brighten our fellow-labourers in the field in any part of the world will likewise brighten and energise every branch of British industry.

3. *On the Variations of Price-Level since* 1850.[1]
By MICHAEL G. MULHALL, *F.S.S.*

Hitherto all efforts to ascertain the variations in the purchasing power of gold, especially since the year 1850, have been futile, because economists could not agree on the best method of fixing a level of prices. Some adopted index numbers, others arbitrarily laid down classifications of merchandise of primary or secondary necessity. But there is only one true way, namely, to take the current market value of the goods that are bought or consumed among nations, and compare the aggregate sum with the amount which the same quantity of goods would have cost at any former date with which it is sought to make a comparison.

The same quantities of products and merchandise consumed annually from 1881 to 1884 would have cost in previous periods, at the prices then ruling, as follows:—

—	Millions £ sterling				
	1841–50	1851–60	1861–70	1871–80	1881–84
Grain	1,419	1,724	1,658	1,547	1,326
Meat	560	628	661	747	830
Hardware	576	525	504	593	384
Dairy products	236	266	303	333	340
Cotton goods	386	335	484	346	302
Woollen goods	263	245	280	268	223
Timber	428	338	338	301	273
Coal	224	241	241	241	189
Leather	218	202	212	188	184
Potatoes	115	125	154	164	181
Wine	86	105	111	111	130
Raw Cotton	76	85	183	101	87
Wool	160	145	125	97	83
Books	120	115	105	87	79
Silks	68	82	104	88	73
Linens, &c.	77	74	78	74	70
Sugar	106	100	106	84	61
Coffee	23	30	38	50	42
Tobacco	29	44	53	38	37
Tea	16	20	24	21	16
Total	5,186	5,429	5,762	5,479	4,910

The above twenty items comprise 90 per cent. of all human industries, as regards products or manufactures, and therefore enable us to arrive at the exact variations of price-level for the whole world, that is the rise or fall in the purchasing power of gold since 1850. The result is as follows:—

Years		Years	
1841–50	100·0	1871–80	105·7
1851–60	104·7	1881–84	94·7
1861–70	111·1		

[1] See *History of Prices since* 1850, by the same author (Longmans & Co.), 1885.

We find, therefore, a fall of $5\frac{1}{4}$ per cent. from the price-level of the decade ending 1850, or nearly 15 per cent. from that of 1861–70. This is much less than people in England generally suppose, because it is the fault of Englishmen to limit their scope of observation to this island, when, by looking around at other nations, we might be better enabled to form a correct judgment.

It is remarkable that if we separate agricultural (including pastoral) products from manufactures, we find the former have risen 11 per cent., the latter fallen 25 per cent., since 1850. The present volume of the world's products at previous prices would have represented the following values:—

Years	Millions £		Ratio	
	Agriculture	Manufactures	Agriculture	Manufactures
1841–50 . . .	2,826	2,360	100	100
1851–60 . . .	3,272	2,157	116	91
1861–70 . . .	3,416	2,346	121	99
1871–80 . . .	3,293	2,186	117	92
1881–84 . . .	3,133	1,777	111	75

Therefore, fifteen shillings will now buy as much manufactures as twenty in the years 1841–50, but in matters of food we should require twenty-two.

As regards the causes which led to the fall in price-level I have nothing now to say, my present purpose having simply been to fix precisely the relative value of gold as compared with merchandise in the thirty-five years that have elapsed since the great discoveries of the precious metal in California and Australia.

FRIDAY, SEPTEMBER 11.

The following Papers were read:—

1. *On the Municipalisation of the Land.* *By* Sir George Campbell, *K.C.S.I., M.P.*

It need hardly be said that the municipalisation of the land is no new-fangled idea, but one of the oldest of human institutions. From the earliest times of which we have historical knowledge the communal tenure was universal both in Europe and in Asia, and in most countries it prevails to the present day. We are specially familiar with it in India.

Such a tenure is by no means inconsistent with individual property; on the contrary, individual possession of the arable land is one of the features of the system. In pastoral times tribes may have held large tracts in actual community; but, as soon as agriculture is introduced, there is always a partition for that purpose. It is true that the jealousy of inequality and unfairness was such that the early law of the village communes required the periodical redistribution of the land according to the recorded ancestral shares, but our experience in India is (and it is the same in Europe) that in course of time this also becomes obsolete; the arable land becomes permanent individual property subject to certain superior and reversionary rights of the community, as also do the sites of dwellings and the curtilages attached, while a tract of grazing and certain rights of wood and water, &c., remain common to the community.

It is for want, I think, of appreciation and understanding of the true communal tenure that in Ireland and elsewhere it seems to be supposed that there is an opposition and antagonism between what is called nationalisation of the land and peasant proprietorship. On the contrary, under the communal system the superior right of the community and the private right to individual holdings exist together,

and are, in fact, the complement and support of one another. It is the old story of the bundle of sticks—united they are strong, separated they are weak.

In this country the old communal system has for the most part gone, and it would be very difficult to replace it throughout the country, but in most self-governing towns it long lingered. In Scotland most of our Royal burghs had considerable land—the 'common good'—till it was alienated by the corrupt Town Councils of former days. And to this day in Scotland the town is usually the superior or ground landlord of the proper municipal area, individual sites being held under the town on 'burgage' tenure. Towns have now extended far beyond those old municipal limits, and can only find room by taking sites from the surrounding landlords. Not only is there an enormous increment of the value of this circumjacent land, unearned by the proprietors and due to the industry of the townspeople, but this land is also subjected to a monopoly value far beyond what it would fetch if freely thrown on the market. Land, which will in no other way fetch 1*l.* or 2*l.* per acre, is not given for building purposes till the pressure is so great that 20*l.*, 30*l.*, or 40*l.* per annum is paid. Hence comes the deprivation of gardens, overcrowding, and many evils which have been recently depicted by the Royal Commission on the Housing of the Poor.

In Ireland and the Highlands of Scotland it will probably be found that the system of very small agricultural holdings requires some communal organisation for many purposes, but I will not enter on that here. Admitting that in the greater part of Britain agriculture has reached a stage which could make agricultural municipalisation on a very large scale very difficult at present, I address myself now to the municipalisation of the land near towns and populous places. The population of this country is now so great and the supply of food from all quarters so enormous that very much of our land is more important from the point of view of health and recreation than for the raising of corn.

Some of us may be inclined to think that no good comes out of Ireland. Yet I believe that nowadays some things are conceded as an indulgence to Ireland which are afterwards found not to be altogether inapplicable to this country. The 'Labourers' Dwellings (Ireland) Act' was looked on with much suspicion. But now, as the result of the report of the Royal Commission on the Housing of the Poor, a new departure in the same direction has been taken in Britain by the Act for the Housing of the Working Classes, which has just passed the Legislature. It contains an important provision enabling town and rural authorities to take up lands, subdivide them, and let them out for cottages and gardens in plots not exceeding half an acre each. That is, I think, a first and very large step towards what I call the municipalisation of the land. Something might also be done to settle labourers on larger crofts in the country, but I leave that for the present.

No one who has paid any attention to the subject can doubt the extreme importance and necessity of giving room to our working classes, both from a sanitary and from a moral point of view. The deprivation of gardens and back yards, the crowding into unhealthy tenements, not only deteriorates the race physically, but drives the men into the public house, the women into dirt and disrepute, the children into the gutter. More room is absolutely required, and more room means more land in decentralised positions connected with the centre by the facilities which modern means supply. If the rent of building land is 30*l.* or 40*l.* or more per acre, gardens and yards are impossible to the working classes; and, therefore, more room is only possible with cheaper land. It would be very difficult, and tend towards socialism and want of self-reliance that the public authority should not only find the land, but build, equip, and maintain the houses on a large scale. What is required is such a tenure that individuals may do so much. At the same time, in crowded communities it is right to maintain a sufficient control over individuals, so as to ensure that one man may so use his own as not to injure others. And it is well that a public revenue should be derived from the land rather than from excessive taxation.

Not only is the monopoly price of land near towns excessive, but the tenure is unsatisfactory. The English system of terminable building leases is one against which modern feeling rebels, and if there is sometimes some advantage in the

regulating power of the ground landlord, it is capricious and uncertain. In Scotland the system of perpetual feus has great advantages; but even there landlords are in many places introducing terminable leases after the English pattern, but shortening their duration. More than that, it is the case not only in the Highlands, but beyond the Highlands, that houses are built by tenants without any tenure at all on mere holdings from year to year. This is especially the case in the great and progressive county of Aberdeen. The smaller farms and crofts with the buildings on them are usually held on this slender title. And great fishing villages all round the coast, inhabited by a very energetic, prosperous, and progressive race, are held equally without any security. The houses are entirely built by the fishermen. They pay for every stick and every stone, yet they are liable to be turned out at the end of every year at the will of the landlord. In and about the prosperous sanitorium of Braemar the old houses have no better tenure, and I am told that on one of the two great estates there for the building of valuable villas no better tenure can be obtained than leases of between thirty and forty years.

The papers presented to Parliament a little time ago regarding the house-tenure of foreign countries show that abroad individual ownership of the occupier is far more common than with us, and the sites are altogether held on a better tenure. But then everywhere in those countries the municipalities, towns, and communes have a much greater control in the common interest, and exercise it much more actively and effectively. That, then, is the model to which I would look in any municipalisation of land—*i.e.*, to vest the superior right of the ground landlord, as it were, in the municipality, with sufficient power of regulation and control, and under the municipality to let out plots for buildings and gardens on a title not altogether absolute, being subject to certain limitations, conditions, and control, but still secure and liable to interference of the public authority only, and not to the caprice of any individual. There would be, in fact, a new burgage tenure something like Scotch feus, with the municipality as superior landlord, and the feu rents would be payable to the municipality.

On a system such as this, well-managed municipalities might, I think, advantageously take up a great deal of land in their neighbourhood, so as to allow of a large extension and secure the benefit of the growing value as the town extends. Some supervision of a central authority may be necessary, but not so much as is imposed by the recent Act. The action of local bodies is there hampered by so many checks and counter-checks that happily the operation of the provisions which I have mentioned may be very limited. Still, the principle of municipalisation is very clearly there, and if the law were worked in a very liberal spirit, scarcely anything more might be required to attain such a municipalisation as I desire, if only the price to be paid for the land could be well settled. *There* is the rub. The fact is, that there are two prices—the price which the land will fetch when thrown on the market and the price which is obtained in driblets, in virtue of a monopoly, by closing the market and saying you shall have nothing till you pay an exorbitant price. The time may come when the divine right of the landlord to the urban increment unearned by him may be called in question. But in present circumstances, it is enough to claim that the price should be, not the arbitrary monopoly price, but the price which a willing seller would get from a willing buyer at the time. Municipalities should be entitled to claim land conveniently situated for extension, and not specially appropriated for demesnes on those terms. With reasonable good management they should sustain no pecuniary loss on such transactions.

If such a system were well introduced, then we may well believe that our crowded and unwholesome towns would expand into pleasant suburbs, with rows of cottages and gardens, such as we see in America and elsewhere, served by tramways, and the homes of an industrious and healthy people, combining their trades with gardens and small crofts, in which, rather than in the public houses, they would spend their spare time. Labour would be combined with recreation, intelligence, good society, and domestic virtues. We should arrive at the true dignity of labour, and avert many evils and many dangers.

2. *The Agriculture of Aberdeenshire.* *By* Colonel INNES.

The paper was mainly occupied by the agriculture of Aberdeenshire as a meat-producing industry, and as typical of the agriculture of the north-east counties of Aberdeenshire.

1. It traced how the export of fat cattle and dead meat for the southern markets by steamer and rail became the staple product of the agriculture of Aberdeenshire.

2. The change which is taking place in this product of fat cattle is, that the stock reared in the county is no longer sufficient to supply the store cattle for fattening, and that an increasing proportion of stores have to be imported.

3. The increasing competition which the meat produced in Aberdeenshire is encountering in the southern markets from foreign fat cattle and dead meat.

4. The remedy suggested. The importation of foreign store cattle to be fattened. The employment of imported cattle food.

5. The anticipated advantages are, (1) that the largely increased production of meat within the same agricultural area will be more profitable, (2) that the supply of the southern markets with meat, by importation of store-cattle, and feeding at home, instead of by importing foreign meat, will add to the fertility of the soil by the consumption of large quantities of imported food; (3) it will at the same time add to the resources of various industries, and to the food of the poorer classes by increased supply of the hides, tallow, and offals.

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3. *The Agricultural Situation.*[1]
By Professor W. FREAM, *B.Sc., F.L.S., F.G.S.*

During the year there has been a sharp and decisive fall in the value of all kinds of agricultural produce. Though this has benefited the poorer classes it has proved most lucrative to the retail dealers in bread and in meat, for the decrease in the cost of these articles to the consumer exhibits an altogether inadequate ratio to the decline in their value to the producer.

The best English wheat has been sold for as little as 30*s.* per imperial quarter, which is the lowest price on record, the lowest price touched during the preceding thirty years having been 37*s.* 7*d.* in 1879, whereas the average price since last year's harvest has been about 33*s.* The fall in the price of wheat is partly attributable to the abundant harvest of 1884, when the yield of wheat was so large that the import of foreign wheat was less than in any year since 1876, and was 17 million cwts. less than in 1883, the shipping trade suffering severely in consequence. In the second week of March last barley and wheat were officially returned as of the same value, namely, 31*s.* 3*d.* per imperial quarter.

Pedigree cattle have undergone a very serious depreciation in value, and in many cases sheep have fallen to half the price they commanded two years ago.

Dairy farming, the last stronghold as it were of our declining agriculture, has been attacked in its most sensitive points, namely, the values of butter and cheese. Butter declined from 20 to 30 per cent. on the quotations of the previous year, and cheese from 20 to 40 per cent. on the preceding year's prices. In August the Cheshire cheese market fairly collapsed.

British farming was probably never in a gloomier condition, for it is not one branch alone but all that are now experiencing depression. Farmers will this year incur enormous financial losses, and it is difficult to discover how, in many cases, rents will be paid.

Taking the United Kingdom as a whole, it appears that during the decade from 1874 to 1884, there was a falling off in the area of arable land of 1,288,413 acres. Simultaneously, the area in permanent pasture increased by 1,936,790 acres. It would seem a startling statement to make that the British Isles are gradually going out of cultivation, and yet it appears that whereas in 1874 the areas under

[1] Published *in extenso* in the *Aberdeen Journal*, and in various agricultural journals.

arable cultivation and permanent pasture were practically equal (23,462,184 and 23,680,416 acres respectively), in 1884 they differed by nearly 3½ millions of acres (22,173,771 and 25,667,206 acres respectively). This change has been accompanied by a diminution of the rural population, though at the same time the total population underwent a marked increase. Thus, the census returns of 1871 gave the number of agricultural labourers in England and Wales as 962,348; ten years later the number had fallen to 870,798, a decrease of 91,550, representing a deficit of 9·5 per cent. on the number in 1871. The number of farmers in England and Wales underwent at the same time a similar decrease of about 10 per cent. Part, perhaps much, of the decrease in the farming population may be due to the more extended use of machinery, for the number of proprietors of agricultural machines let for hire, and of the attendants upon them, increased from 55 in 1851, to 1,441 in 1861, to 2,160 in 1871, and to 4,260 in 1881.

Perhaps the boldest course to take with regard to the state of agriculture is to look upon the depression as normal and permanent, and then to discover, if possible, how this new order of things may best be faced. A further fall in rents seems inevitable, unless landowners prefer the alternative of cultivating the land themselves. It is desirable that the producer and the consumer should be brought into closer relationship, for the middleman is thriving well at the expense of both. A perfect and rigid system of quarantine is desirable for the better protection of live stock from imported disease. Our home dairy practice requires to be raised to a distinctly higher level; at present Denmark is ahead of us in butter-making, and Canada in cheese-making. But in each country named the Government has fostered these industries by the advancement of technical education; our own Government is quite apathetic in the matter. The losses inflicted on crops and live stock by the ravages of insect, fungoid, and other pests, are stupendous, but this country possesses no organisation by means of which farmers could be instructed, warned, and advised on such matters. For these and allied purposes an efficiently equipped Department of Agriculture would prove of incalculable value.

After a brief description of the United States Department of Agriculture, and of the Department of Agriculture of Manitoba, the paper concluded by advocating the equipment of a Department of Agriculture for the United Kingdom, placed under the control of a responsible Minister of Agriculture, or of Agriculture and Commerce. Such a department could probably reach and influence the individual farmer in a manner which, for efficiency, no existing agency has been able to approach; it could diffuse valuable and necessary information of a simple and easily assimilable character, which would in time become embodied in the general practice of those by whom it would be received; it could collect and rapidly digest information from all the agricultural districts of the United Kingdom, and then issue, in the form of bulletins, timely warning on many matters which in the absence of such warning might have led to loss; and it could, under energetic and intelligent management, raise the entire agricultural industry of this kingdom to a higher level than it has ever yet attained. In the diminution of preventible losses alone such a department would prove invaluable. The agricultural functions now variously exercised by the Board of Trade, the Science and Art Department, and the Veterinary (or Agricultural) Department of the Privy Council, might well be transferred to it, but such a department would utterly fail of its object were it allowed to sink to the level of a mere record office. It should be an active, living, and progressive organisation, and the results it would then achieve would probably in a very few years amply justify the fact of its establishment and the cost of its maintenance.

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4. *On recent Changes in Scottish Agriculture. By* Major P. G. Craigie.

The author claimed the right of Agriculture in its present depression to whatever aid science can afford. Intelligent use has been made in Scotland already of the teaching of scientific experiments. But before the help of any specific science is invoked in any new direction, it is indispensable that the facts and figures of the agricultural situation should be more clearly appreciated than they are by

most of those who offer advice to the practical farmer in his present straits. It must therefore be right to discuss first of all, in this Section of Economic Science and Statistics, what the position is, both relatively and absolutely, before any confident prescription can be offered for the ills of Scottish agriculture. To obtain some sure footing of a statistical nature, some means of contrasting the leading features of the agricultural situation as it presents itself in Scotland with the position of matters elsewhere, and some knowledge of wherein and to what extent the use made of the soil differs from the previous practice, is necessary if we are even to attempt to offer a diagnosis of the disease from which agriculture is suffering. This, and not any ambitious attempt to formulate hypothetical solutions of the land question, or to advise the Scottish farmer—proverbially the most shrewd of agriculturists—how to conduct his business, is the limited aim of the paper.

Partly owing to the character of the surface and partly to the form of our yearly returns, we know much less about the use and distribution of the soil in Scotland than in England. Only the proportions technically spoken of as 'under cultivation,' *i.e.* under some actual crop, bare fallow, or grass other than mountain or heath land, are accounted for annually. In England three-fourths of the surface come within this category, but only one-fourth in Scotland, so that for three acres out of every four in the latter case we have no information. Speaking more accurately, the measured surface of England, excluding Wales, is 32,597,000 acres, whereof 24,844,000 acres are regarded as cultivated; and the measured surface of Scotland is 19,467,000, whereof but 4,812,000 is in this sense cultivated. Barely 25 out of every 100 acres is thus reported on in Scotland, whereas in England it is only 25 out of every 100 that fails to be reported on. Yet it is at once evident from the live stock in the two countries that the official figures exclude much land used for the grazing of sheep, in some instances even of cattle and ponies. Our official tables therefore offering a contrast between the stock kept on each 100 cultivated acres in the two countries are misleading. It is the disregard of mountain pastures which makes it appear that England has of sheep 66, Wales 95, and Scotland 145 to each hundred acres. As a matter of fact, in the valuable statistics collected by the Highland and Agricultural Society in 1854, the 'sheepwalks' not entered in our annual statistics now, then covered 6,531,000 acres, or an area larger by one-third than all the cultivated land at present reported on. An enlargement of our statistics, which would supply information as to any changes in this branch of Scottish agriculture is therefore from every point of view desirable.

Excluding these mountain pastures, the small area of permanent pasture, one acre for three under the plough is noted, instead of one for one as in England. The large use of rotation grass which balances this feature is commented on and explained, a third, in place of a tenth as in England, of the cultivated area being thus utilised. The Scotch percentage of cereals in that area is 28·6 per cent. against 26·8 per cent. in England, but only 5 per cent. of the land in corn is used for wheat, as against 38 per cent. in England, oats occupying three acres out of every four.

Contrasts between the agricultural distribution of the soil thirty years ago, as shown by the Highland and Agricultural Society's statistics in 1855, and the official figures for 1869 and 1884, were then given, and tables were compiled exhibiting the parallel changes in England and in Ireland in the same interval. These showed that the arable area has increased in Scotland, though largely declining in England in the past fifteen years, permanent grass increasing very little in the North, while it shows a 20 per cent. increase in the South. Wheat-growing in Scotland, always a microscopic fraction of the national industry, had dropped from 191,300 acres in 1855 to 135,700 acres in 1869, and now to 68,700 acres in 1884, but the difference has gone in a large degree into other cereals, and it was specially noted that much of the decrease had occurred, not in consequence of the present depression, but before 1869. Tables and details showing for particular counties the changes over this period in greater detail were offered, and the characteristics of Scotch farming and the relation of the Scotch population to the small local wheat supply was noted.

The paper dealt with the question of suggested decline in cereal produce per

acre in Scotland. Contrasting the Highland Society's statistics in 1855, with recent inquiries, such as that undertaken by Major Craigie himself in 1882, and with the latest official figures the conclusion arrived at was that where wheat is still grown now, of course only on the best land, the yield is 31 or 32 bushels per acre against only $26\frac{1}{2}$ thirty years ago, barley yielding $35\frac{3}{4}$ against $32\frac{3}{4}$ at that date, while oats also advanced by several bushels, so that no grounds would appear to exist for the idea of a declining produce per acre.

After dealing with questions of the greatly altered money value of the gross outcome of the several crops—wheat, which brought in over 2,000,000*l.* in 1855, now contributing 455,000*l.* only to the aggregate receipts of the year, and both oats and barley fetching lower figures—an estimate of the acreable value at the present time was given. This the writer placed, taking all cereals into account, at 4*l.* 16*s.* per acre, as against 5*l.* 9*s.* 6*d.* thirty years ago.

Attention was then devoted to the changes in the live stock of Scottish farms—both generally and in detail by means of tables, and the parallel changes in England and Ireland were noted. Cattle had, on the whole, increased, and sheep, which were more numerous in 1869 than in 1855, are but slightly under the higher level now. This was contrasted with the English reduction of 17 per cent. in the flocks of that country. This was a matter specially worthy to be noted in view of the assertion that deer were taking the place of sheep. There were apparently a million more sheep in Scotland in 1869, than in 1855, and in the next 15 years up to 1884, the decline was only from 6,995,000 to 6,983,000, or 12,000 head; while in England in this period, the sheep were 3,394,000 fewer, and in Ireland 1,400,000 fewer. There was far less falling off in the Scottish flocks, than those of other European countries.

The question was then discussed as to what was the yearly out-turn of meat which Scottish farmers produce, and estimates varying from 160,000 to 140,000 tons yearly were mentioned and explained, and the sufficiency of the scale applied to the United Kingdom generally for the particular features of Scotch meat production was discussed. Scotland was shown to be, if a largely wheat-importing country, a distinctly meat-exporting one, and an opinion expressed that the breeding of stock yet more largely in Scotland would be advisable and was perfectly practicable.

SATURDAY, SEPTEMBER 12.

The following Papers were read :—

1. *On the International Forestry Exhibition.* *By* Dr. Crombie Brown.

The author said the richness and variety of the International Exhibition in Edinburgh, notwithstanding its deficiency, was fairly representative of British notions of arboriculture and forest economy; but the ignoring of sylviculture supplied an argument for the establishment of a National School of Forestry, in which might be taught and applied the advanced forest science of the day. It must be remembered that there was a great difference between arboriculture and sylviculture; and far-reaching results were to be expected from the scientific management of forests. There was, therefore, great need for a National School of Forestry. The great benefits which might reasonably be expected to follow therefrom were evident to everyone acquainted with the subject. It was chiefly the requirement of British colonies and lands similarly situated for the exploitation of forests that impressed him with the importance of having a National School of Forestry organised. The interest which our country had in the improvement of the forest economy of Great Britain supplied an equally urgent reason for such a measure being adopted. In every place where the British rule extended, except in India, there had been a ruinous neglect of forests. In South Africa alone millions of acres had been made desert from the destruction of the indigenous forests. This neglect

was a striking contrast to the interest taken in arboriculture and sylviculture in France, Prussia, Switzerland, and Russia. Colleges there were provided with a complete staff of accomplished professors, who trained youths of good birth to become State foresters. He did not see any immediate prospect of the establishment of a School of Forestry; attention, however, had been called to the matter in Parliament; and such a school must be established sooner or later. In Edinburgh a movement had been set afoot by the Marquis of Lothian and other gentlemen for raising 10,000*l.* for the exhibition of many valuable objects entrusted to them, and the establishment of a lectureship or professorship of forestry. The 10,000*l.*, however, was slow in coming in.[1]

2. *What is Capital?* *By* W. WESTGARTH.

The author alluded to the wide divergencies of view upon this question amongst leading economists. On behalf of commerce and banking he challenged the correctness of these views. Capital was usually defined by economists as consisting of things used in production, and as being only that part of wealth which is applied to produce further wealth. The same thing may be capital and not capital, according to the hands it is in. Thus, a manufacturer deals with capital, but not a shopkeeper, the former being a producer, but the latter only a distributor. Mr. Westgarth holds that this is only a conventional capital created in the minds of economists, and having no existence elsewhere. No doubt much confusion arose from the free and loose use, both in and out of business, of the term capital. Thus we had fixed capital, liability capital, and so on; but, holding the word to mean now universally the ready fund of business life, we ought, for clearness' sake, to avoid, in economic science, to give the term capital to anything else but this fund. No doubt the term capital had, originally and derivatively, the meaning expressed by 'fixed capital,' and the business fund might be viewed as an interloper in appropriating the name. But none the less we must accept facts. The interloper cannot now be dislodged, and we must not continue to call different things by one and the same name. What, then, is this capital fund? It is substantially the stocks of trading, called into existence, and maintained in existence, by the wants of trading or exchange. Every trader must have stock of his particular vocation, and this stock collectively is the society's capital. The merchandise and money and rolling-stock of a country's commerce constitute its capital fund. Money is only a particular form of merchandise. This capital fund increases or diminishes according to the circumstances of the trading, as requiring more or less stock. On the one hand is the constant tendency to economise capital so as to save the cost of holding it; on the other hand capital is ever increased by the constant effort to increase profit through extending the scale of business, and thus reducing relatively the expenses. We have thus the elements of the limitation or law of capital. For instance, the Suez Canal is cut in order, by the reduced time, to economise capital in shipping and cargo. But these economies themselves so increase the trading, that still more ships and cargoes than before are the result. The causes which economise or reduce capital are exceeded in effect by the causes which increase it; and thus, while increased profit is the object, increased capital is the concurrent result. We have here the elements of a 'law of capital.'

3. *On Methods of ascertaining Variations in the Rates of Birth, Death, and Marriage.* *By* F. Y. EDGEWORTH.

This paper is designed as a study in that branch of statistics which may be described as the method of eliminating chance by means of the mathematical theory of errors. In illustration of the general principle, the following example is discussed:—Suppose that the mean age at death of a hundred (or a thousand) total abstainers, taken from the general population above a certain age, is greater by a year or so than that of the general population, what presumption is there that

[1] Printed in *Forestry*, November 1885.

this difference is not accidental? It is shown that the answer depends upon a certain constant, or co-efficient, which might be calculated from life-tables. This constant enables us to find the probability that the mean age at death of a hundred (or a thousand) persons taken at random, would deviate to an assigned extent from the mean age at death of the general population. This all-important constant may be defined as one or other of the following correlated quantities: the *precision*, the *probable error*, the *modulus*, or (as the writer proposes to call the square of the modulus) the *fluctuation*.

Two problems in vital statistics, in the case of which the discovery of the requisite constant presents peculiar difficulties, form the special subject of this study.

I. Suppose out of a population, resident in the same place in the same year, there are taken at random several groups, and the death-rates calculated for each of those groups; according to what *modulus* would these figures fluctuate? It is required to elicit this answer from the Registrar-General's returns, which give only death-rates for different years and different places. The answer to this problem may be used to verify inferences concerning the relative unhealthiness of different occupations. But a wider utility attends the solution of the problem. The fact that the different methods by which it may be attacked lead to the same result is calculated to give us confidence in handling the mathematical instruments of statistics. We realise that to each class of phenomenon there appertains in general a tolerably constant co-efficient of fluctuation; which, having been obtained by observation, we shall be able to employ this datum of past experience to test future statistical inductions.

II. The second problem exemplified is to determine whether a given series of statistical returns indicates *progress*. Consider a set of figures representing the mortality of a certain population for several consecutive years. The theory of the *modulus* can determine whether an appearance of increase or decrease in these returns corresponds to a real difference in the conditions of life. The indications afforded by scientific method are apt to differ considerably from the guesswork of common sense.[1]

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4. *On the Application of Biology to Economics.* *By* PATRICK GEDDES.

Since the progress of any order of ideas proceeds mainly from within, even heresies arising by a reversal of former beliefs, it is not to be wondered at if economists of all schools, orthodox or heterodox alike, are little attracted by the proposal to translate the propositions they debate from the time-honoured vernacular into the language of scientific specialists. Yet to point to this round-about way of simplifying matters is the object of the present paper. Not only, however, does biology owe much to economics—witness such a principle as the physiological division of labour—but the author of the 'Origin of Species' has traced its direct filiation to Malthus' theory of population.

A classic account of this relation is to be found in Mr. Spencer's well-known popular work 'On the Study of Sociology,' and the importance of the subject has often been insisted upon—witness Dr. Ingram's memorable presidential address of 1878, or his recent article 'Political Economy.' But as a recent reviewer scornfully asks, what have physics or biology to do with land-tenure, with taxation, the depreciation of silver, the rate of wages, the thousand and one problems of the economist?—but the reply is easy: what biology seeks to deal with are the fundamental conceptions of the subject, not their application to concrete details. Thus the biologist, while as yet at least wholly shrinking from interference with matters too high for him, will in no wise be restrained from claiming what the economist lumps as 'competition' as a form of the general struggle for existence, and seeking to analyse it, or, dissatisfied with the loose and popular notion of 'progress,' endeavouring to distinguish whether it means evolution or degeneration of population and their surroundings in each special case. When this is done the air becomes clearer: we see how, for instance, the dispute preceding the passing of

[1] Printed *in extenso* in the *Journal of the Statistical Society* for January, 1886.

the Factory Acts was not really at all a struggle between 'economic science' on the one hand and 'mere sentiment' on the other, but turned upon subordinating the lower ideal of physical economics—that of maximum production in given time—to the higher ideal of biological economics—that of maintenance and evolution of the population. Again, in the current dispute between individualist and socialist, we at once see that what the former has really taken his stand upon is simply the law of survival of the fittest, the principle of natural selection; while the socialist position has its essential base in the later but equally valid conception of the practicability of artificial selection. And thus for the biologist a line of research is clear—to unite and define these two vaguely-discerned positions, and to apply them to the interpretation of civilised society, as he already does not only for animals but for the lower races.

Nor is the general course of practical action less evident: the biologist must side with the individualist against the socialist in recognising that man can never shake himself wholly free from the iron grip of nature, yet, undiscouraged by this, since recognising the vast modifiability of life through its surroundings, must yet encourage the socialist in every rational effort to subordinate natural to artificial selection, and raise the struggle into the culture of existence.

But 'while philosophers are disputing about the government of men, hunger and love are performing the task.' From the physiological standpoint all functions are summed into those two—into nutrition and reproduction, into individual life and the reproduction of it. Thus the economist, whether taking sides for or against Malthus, cannot seriously deny that he has entered on a biological inquiry, and that one of fundamental importance to his own science. Now Malthus' principles are: (1) that population tends to outrun subsistence, but meets with checks in so doing; these checks being (2) *positive*, as war, famine, disease, &c.; or (3) *preventive* or moral. But the essential work of Darwin has lain in developing the first of these conceptions into that of the struggle for existence, as in recasting the second and third into natural and artificial selection respectively. Yet can it be urged that any economist has adequately applied these to theory or practice? Nay, more; perhaps the most valuable result of Mr. Spencer's biological labours lies in the demonstration of a limit law of population wider than those discerned by either Malthus or Darwin, namely that, other things equal, '*multiplication and individuation vary inversely*'; that is to say, the rate of reproduction of all living beings tends to be lowered as their individual development is raised, and conversely. Now, the practical outcomes of these three states of the theory of population are very different: for the economist who reads only Malthus there is no hope of curing the miseries due to over-population save by preventive checks of one sort or other; yet if he goes on to read Darwin, the advantage to the species of this struggle among the individuals becomes evident, and *laisser-faire* tends to resume the ascendant. Here in our day the discussion rests. Yet with what reason can they omit taking into account the law expounded by Spencer? And if this step be made, if the economist once really grasps the modern rather than the early theory of population, practical action at once assumes a new and higher aspect. For if individual life and rate of multiplication do indeed vary inversely, we have here the secret of the connection of poverty with progress—it lies primarily in the department of production, not that of distribution, let reformers of the latter say what they will; and the practical economists who would increase the well-being rather than the mere number of the population, must attempt a vast proportional increase in the industries which elevate life over those which merely maintain it, must make his ideal of progress for a long time lie rather in raising quality of production over mere quantity of it. Without keeping this clearly in view, the mere cheapening of food only multiplies poverty without increasing it, and our modest utopia of an adequate supply of penny dinners will but lead to an appalling demand for farthing ones. Yet reversed, the same iron law of wages, for such it is under its biological form, furnishes the economic justification of morals and of culture, the only yet sufficient hope of a general elevation of society.

MONDAY, SEPTEMBER 14.

The following Papers were read:—

1. *On the Use of Index Numbers in the Investigation of Trade Statistics. By* STEPHEN BOURNE, *F.S.S.*—See Reports, p. 859.

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2. *On Depression of Prices and Results of Economy of Production, and on the Prospect of Recovery. By* HYDE CLARKE, *F.S.S.*

The author said that the expectations in 1884 of the sale of the corn crops in the United States and Canada had not been realised, nor were hopes of recovery to be built on the crops of 1885. The sale in the European market of American and other imported corn is limited by the fact that the consumption by human beings (and by animals) is itself limited by what the individual can consume, which is a natural maximum not dependent on price. The amount to be supplied is the deficiency each year on the local crops, which in most European countries meet their own wants, and in the eastern districts allow of export. Corn, too, cannot, like fibres or metals, be stocked for a long time.

Corn, sugar, and coffee are now produced in large quantities, because all the best producing countries are laid open by cheap railways, and the freight to the ocean markets is also reduced.

The effective cause of the great reduction in production and transport is due to the reduction in the cost of steel and iron, consequent on the inventions of Bessemer, Siemens, Thomas, Gilchrist, and others. Whatever the quantity of gold may be, the former price of steel in relation to other commodities will not be regained. As steel or steel iron rails can be made for one-tenth of the cost of thirty years ago, this is an economical fact to be dealt with. Cheap railways and cheap ocean steamers are now making their influence felt.

With regard to gold coinage, the effect of any supposed short supply cannot be measured from one year's supply, or five, or ten years', as the effect has to be calculated on the whole mass of gold coinage existing in the world, whatever that may be. Gold is a metal coined over and over again, sometimes for centuries, and the coinage of a year is in reality in a great degree recoinage. The wear and tear on coinage is much less in the whole world than is usually estimated, as much coin is hoarded, or is subject to sluggish circulation. Manufacturers of gold take new coins and make them into rings, chains, jewellery, and give back supplies of bullion to the mint. The wear and tear of manufactured gold is also limited. Manufactured gold and coinage act and react on each other, but a positive pressure on coinage is supplied from manufactured gold.

It is not possible to ascertain the real and effective total of gold coin in circulation in the world at any moment, and if we could ascertain that, we do not thereby learn the ratio of its efficiency. This is not immediately relevant to its quantity, but to the greater or less rapidity in its circulation or turn-over, dependent on sluggishness or energy of trade, panic, war, famine, hoarding, and many other causes. At present no practical evidence has been adduced that a diminished supply of gold is the cause of lower prices.

With regard to the question of recovery, it will ultimately depend on the readjustment of the new economical conditions. Temporary fluctuations of price may be caused, as was seen this year, by war and rumours of war; also by short crops, or by the discovery of some new mineral commodity. The course of economical events is, however, in the direction of discoveries still further diminishing the amount of labour required for production. The low prices may, however, assist in their own readjustment. At the present moment half the population of the world—in India, China, and Japan, five hundred millions in number—are under the influence of old traditional prices, which in some cases give daily wages of *2d.*

As these rates for wages and commodities are raised to the European standard, and they have been rising of late years, the people will have a larger exchangeable surplus for the purchase of goods, and a diminished power of competitors in production. Indian wheat is raised with wages of $2\frac{1}{2}d.$ per day.

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3. *On Customs Tariffs.* *By* A. E. Bateman.

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4. *How its Fiscal Policy may affect the Prosperity of a Nation.*[1] *By* Alexander Forbes.

The author said that if free trade could be universal, it would be indisputably better for Great Britain and all other nations; but it will never become so, as no two nations are similar, either in their position or products, and each will always naturally follow that fiscal policy which recommends itself most to its own individual interests.

It was advantageous for nations not to have a hard and fast fiscal policy, because without it, they could the better maintain their bargaining powers with other States.

It was this bargaining which England by her pronounced free trade had lost, and the loss of which was the principal if not sole cause of our diminishing and unremunerative export trade, and consequent commercial depression and agricultural distress.

England had only to announce that she would treat every country in future as she was treated by it to have the whole world competing for her trade, and willing to do business on the principle of reciprocity. Since 1846 we had as a nation followed too much the policy of studying the interests of the mere consumer, an extraordinary fallacy for a practical and manufacturing people. If our artisans had to pay *8d.* for the 4lb. loaf, and had a shilling to buy it with, it was surely better than that they should be offered for *6d.* what they were through want of employment without the means of purchasing.

The fiscal policy of a State should be guided by the same principles as controlled a business man in his own relations. The latter preferred to give his orders to such as were customers of his own, even although in some cases he might more advantageously place those orders elsewhere, and so gain an immediate partial benefit, at the cost of a subsequent permanent loss.

If the customs duties imposed by other countries with whom we traded were swept away, the demand for goods of British manufacture would be enormously increased.

If we could not induce foreign countries to trade with us on the principle of reciprocal free trade, let us at least place ourselves on an equality with them, and take advantage of the opportunities of making them share part of our heavy taxation by imposing customs duties on the goods they sent into our markets.

If statesmen would not initiate legislation in this direction for fear of bringing disaster to their party, the day was not far distant when the working men would take the question of our fiscal policy into their own hands.

It was quite evident from our experience of forty years, that through mere example we were powerless to induce other countries to adopt free trade principles as we understand them, and it was equally manifest that if we conceded to foreigners facilities to trade with us which they in turn refused to reciprocate, we must as a manufacturing and commercial nation be serious losers.

For not only did the almost prohibitory tariffs imposed by foreign nations preclude our trafficking profitably with them, but, by our own fiscal policy, our home manufacturers did not enjoy in their own market their legitimate trade, through our encouraging the unfettered and ever-increasing competition of foreign producers, whilst we were at the same time, by not imposing customs duties on

[1] Published *in extenso* by John Avery & Co. (Limited), Aberdeen.

what they sent us, depriving our exchequer of an enormous source of revenue which would tend to greatly lessen our imperial taxation.

The outcome of such a policy as Britain is at present following must ultimately disable her from supporting her present population, without which she cannot long maintain her independence, and with the loss of it, at no distant date, must follow all the privileges and advantages which accompany and flow from nationality and empire.

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5. *On the Incidence of Imperial Taxation.* *By* Dr. W. A. Hunter.

The object of the paper, the author said, was to determine with as close an approximation to accuracy as our information admitted in what manner the burden of Imperial taxation was borne by the richer and the poorer classes of the community. The gross income for the year ending March 1882—the census year—was, in round numbers, 80 millions, of which 10 millions were receipts not in the nature of taxation. The remaining 70 millions consisted of a sum of $43\frac{1}{3}$ millions raised from tea, coffee, tobacco, and spirits, forming a burden on all classes of the community. It was, of course, true that a poor man who consumed none of these articles almost entirely escaped any share of this burden; but the same remark was equally true if he was a rich man. The balance of $26\frac{2}{3}$ millions was raised by taxes that fell upon a limited class, which was nearly, but not altogether, co-extensive with the class of persons liable to pay income-tax. These taxes comprehended income-tax, house duty, some of the excise licences, railway duties, death duties, stamps, and wines. Some of these taxes fell to a certain extent also upon incomes under 150*l.* a year, so that the sum he had stated at least somewhat exaggerated the amount of the contribution made by the well-to-do classes; but, in order to weight the scales as much in favour of the rich as possible, he credited them with the whole of the taxation. The class represented by the income-tax payers amounted to six millions of people, and the rest of the population to 29 millions. The gross income of the former class he estimated at 650 millions. It must be remembered, however, that in the Inland Revenue returns a great many under estimates occurred which eluded the vigilance of tax-gathers, this being especially the case as regarded foreign securities. But taxation ought not to be based on the gross income. The deduction allowed by the Income Tax Commissioners of 120*l.* a year on incomes under 400*l.* was excessive. Mr. Giffen estimated 12*l.* per head as the reasonable sum that ought to be deducted before one could fairly assess the taxable income. He was not prepared to say that 12*l.* was excessive, but he proposed to put it at the somewhat lower figure of 10*l.* This would give a total of 60 millions to deduct from the 650 millions, or a total taxable income of 590 millions. The total sum paid in taxation by this class, including their share of indirect taxation, was 34 millions, which, on 590 millions, amounted to 5*l.* 15*s.* 3*d.* per cent. It is not easy, Dr. Hunter went on to say, to ascertain the aggregate income of the 29 millions of people whose income does not bring them within Schedule D. Two estimates have been made—one by Mr. Giffen, the other by Professor Leone Levi—of the gross earnings of the working class, a class that corresponds very nearly to the 29 millions. Mr. Levi puts the total at 520 millions; Mr. Giffen at 620 millions—an enormous discrepancy. Mr. Giffen's figures would give an average of 21*l.* 10*s.* per head, or more than 100 guineas for every group of five persons. Such an estimate is hardly consistent with the experience of those who are acquainted with the condition of the working classes. I have endeavoured to test those figures, and have obtained a return of the wages under 150*l.* a year from the Northern Co-operative Company, paid under the following departments:—grocery, bakery, clothiery, butchery, boot and shoe, meal mill, coal, stable, watching and lighting, and counting-houses. The proportion of men employed is somewhat higher than the average; the proportion of women less, and that of boys and girls greater than the average. Although in some occupations men may earn higher wages than those employed at the co-operative stores, yet, having regard to the lower wages paid in rural districts and to the poverty of Ireland, there can be no doubt that the earnings of the employés exceed the average of the whole country.

Correcting the returns so as to make the proportion of men, boys, girls, and women the same as the average proportion throughout the United Kingdom, and adding the due proportion of persons unemployed and maintained by the employés, I find that the average annual earnings per head amount to $19\frac{1}{3}l.$ Upon this basis the gross earnings of the non-income-tax-paying population would amount to 560 millions per annum. There seems no reason to believe that this is too low an estimate. From this sum of 560 millions of gross income we must make a deduction of $10l.$ per head, as we have already done in the case of the income-tax-paying class. This gives us 270 millions of taxable income, of which 36 millions is paid in taxation, a sum equal to $13l.$ $6s.$ $8d.$ per cent. on the income of the poorer class, as compared with $5l.$ $15s.$ $3d.$ per cent. on the income of those who are fortunate enough to require the attention of the Inland Revenue Commissioners. The conclusion, therefore, is that the poorer classes of the population are taxed more than twice as much as the richer class in proportion to their taxable income. Or the result may be stated thus. The poorer class, having regard to their taxable income, ought to contribute about 22 millions a year, whereas they are made to pay 36 millions; and the richer class, who ought to pay 48 millions, escape with a contribution of 34 millions. In order to equalise taxation, it would be necessary to reduce the Customs and Excise to the extent of 15 or 16 millions a year. These figures, however, fail to give an adequate conception of the extent of the burdens actually thrown on the poorer classes. The amount received by the Government from the richer classes is about equal to that which is paid by the latter; but the amount paid by the poorer classes is far in excess of that which is received by the Chancellor of the Exchequer. It is the nature of all taxation of commodities to take more from the taxpayer than is received by the tax-gatherer. Dealers in articles thus taxed require a larger capital for their business, and the cost of the article is enhanced by an inevitable allowance for interest and risk. The Chancellor of the Exchequer receives 36 millions from the poorer classes, but the cost of the articles which they purchase is enhanced by considerably more than 36 millions. This increase cannot be put at less than 25 per cent. The real burden of taxation is thus raised to 45 millions, or nearly 17 per cent. on the taxable income of those who make less than $150l.$ per annum. In the light of these facts the protest that is sometimes raised against graduated taxation appears somewhat out of place. We have graduated taxation, only instead of increasing the burden of taxation in proportion to wealth, we increase it in proportion to poverty. The more able a man is to pay the less is he taxed; the less able he is to pay the more is he taxed.

TUESDAY, SEPTEMBER 15.

The following Papers were read:—

1. *State Guarantee of War Risks. By* JOHN CORRY.

The object of this paper is to advocate the advisability of war risks at sea being guaranteed by the State, instead of as at present being covered by special arrangements with individual underwriters. The author, after referring to the enormous development of our trade, points out how largely we are dependent upon foreign sources both for the supply of our food and raw materials, and how helpless we would be, in the event of war with one or more of the Great Powers, if we were unable to maintain our communications abroad. He refers to instances in which Governments have paid compensation for losses sustained through the operations of war, particularly in the case of the Alabama claims, the bombardment of Alexandria, and the French Indemnity of 1871. A State guarantee against war risks at sea would therefore be merely an extension of a principle which has been already admitted. One of the great dangers to be avoided is the transfer of our tonnage to neutral flags in consequence of the extra premiums necessary to meet war risks.

The author is of opinion that if the volume of our trade were once diverted from its present channels it would be very difficult, if not impossible, to restore it. As a great manufacturing country we are not only dependent upon the economic supply of raw materials, but also upon having sufficient outlets for our finished goods. If the raw materials were not forthcoming the temporary stoppage of our industries would undoubtedly lead to a transference of a large portion of our trade to foreign countries. The author further considers that a State guarantee against war risks would tend to strengthen our relations with our colonies and dependencies, and might lead to a consolidation of the whole empire. In order to safeguard the great interest involved, some improvements would be required in our navy, but the author does not consider that the maintenance of a huge standing army would become a necessity for this country. The cost of war risks must eventually be borne by the nation at large, but if these risks were undertaken by the Government the author maintains that the expense would be vastly less than that which would be incurred through extra premiums and the attendant evils in the event of a great war breaking out.

The objections to the proposal, he maintains, are more apparent than real, and any difficulties could be easily overcome in carrying out the details by principles of procedure which are already well understood. The author claims that this subject is not brought forward in the interest of any particular trade, but upon economic and national grounds. He sums up with the following propositions, which convey a concise statement of his views:—

The whole question can be practically summarised in the following propositions:—

1st. That as the existence of this country absolutely depends on foreign supplies of food and materials anything that would risk the failure or enhance the cost of those supplies must be a national loss.

2nd. That as the trade and carriage is now mainly in British hands it is all important that it should so continue, and not be transferred to, or get into the hands of, our foreign competitors.

3rd. That the international effect of such a declaration as we have advocated would be highly advantageous to our commerce throughout the world, and would prevent neutral nations taking that selfish interest in our position which the hope of future gain might encourage them to show. If any nation expected to gain large material advantages by our being engaged in war we could not as readily look for its sympathy or co-operation.

4th. That if a large amount of our tonnage was transferred to neutral flags, or the neutral flag was largely engaged in our carrying trade, the volume of trade thus once shifted would be very difficult, if not impossible, to restore.

5th. That the cost to the consumers, if Government failed to meet the emergency in case of war, would be enormously enhanced directly and indirectly.

6th. That the effect of such a declaration would tend in the strongest way to bind our colonies and dependencies together, and to unite them to this country.

The products of our colonies and dependencies are now so vast and varied that we could soon be independent of all other sources of supply.

7th. That as the power of machinery has so much reduced the special advantages or facilities which we as a nation have enjoyed over others in the way of manufacturing, any temporary disadvantage to, or disarrangement of, our trade might direct it into other channels, from which it could not afterwards be recovered.

I will only add that the question of indemnity against war risks has not been brought forward here with the idea of benefiting any particular trade, but on account of its direct bearing upon the economic supply of food and rough materials, and the distribution of our manufactures throughout the world.

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2. *On the British Standard of Value.* *By* Dana Horton.

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3. *Sliding Scales in the Coal Industry.*[1] *By* Professor J. E. C. Munro.

There are at least eight sliding-scales in use in the coal industry, viz.: the Durham scale of 1884; the Cumberland scale of 1884; the Northumberland scale of 1883; the Monmouthshire and South Wales Association scale of 1882; the Ocean scale of 1882; the Ferndale scale of 1882; the Somersetshire scale of 1876; the Bedworth scale of 1879.

The following scales have now been abandoned: the North Wales scale of 1880; the South Staffordshire scale; the West Yorkshire scale of 1880; the Shropshire scale.

The number of miners in the United Kingdom is about half a million, and of these 123,000 have their wages governed by sliding-scales. A sliding-scale is based on two standards: (1) a standard price of coal, and (2) a standard of wages, the latter being payable when the former is realised. As the price of coal falls above or below the standard price, wages fall or rise above the standard wages. A certain agreed variation must take place in the price of coal (*e.g.* 4*d.*) before any variation occurs in wages; accounts being examined every three or four months in order to ascertain if any variation has occurred during the previous period.

The different standard prices adopted by the existing scales are as follows:—Durham, 3*s.* 10*d.* and under 4*s.*; Cumberland, 4*s.* 6·19*d.* and under 4*s.* 7·69*d.*; Northumberland, 4*s.* 8*d.* and under 4*s.* 10*d.*; Association, 7*s.* 8*d.* and under 8*s.*; Ferndale, 8*s.*: Ocean, 10*s.* and under 10*s.* 4½*d.*; Somerset, 10*s.*; Bedworth, under 5*s.* 6*d.*

The variations in pıices that result in variations in wages are as follows:—

—	For every rise or fall of	Wages are to rise or fall: Hewers, Enginemen, Mechanics, Cokemen, and Banksmen	Wages are to rise or fall: Other Surfacemen
	s. d.	Per cent.	Per cent.
Durham (Standard 3*s.* 10*d.* and under 4*s.*) . .	0 2	1¼	1
Between 5*s.* 10*d.* and 6*s.* 10*d.* . . .	0 2	2½	2
Northumberland (Standard 4*s.* 8*d.* & under 4*s.* 10*d.*)	0 2	1¼	1
At 6*s.*, 6*s.* 4*d.*, 7*s.* 2*d.*, 7*s.* 8*d.*, 8*s.* 6*d.* & 9*s.*	0 2	2½	2
		Hewers. Per cent.	
Cumberland (Standard 4*s.* 6*d.*·19)	0 1½	1¼	
Above 6*s.* 6*d.*·19	0 2	1¼	
Association (Standard 7*s.* 8*d.* and under 8*s.*) .	0 4	2½	
Ocean (Standard 10*s.* and under 10*s.* 4½*d.*)			
Under the standard	0 4½	2½	
Above the standard	0 4½	1¼	
Ferndale	0 4	2½	
At 11*s.* 4*d.* and 11*s.* 8*d.*	0 4	1¼	
Bedworth (Standard under 5*s.* 6*d.*)	0 3	1*d.* per day.	
Somerset (Standard 10*s.*)			
For every rise or fall in price, wages are to rise and fall at the rate of .	1 0	7½ per cent.	

In some districts allowances are made to the miners in addition to their wages. In Durham and Northumberland hewers receive a free house and firing. At the

[1] Published *in extenso* by John Heywood & Co., London and Manchester.

Bedworth Collieries hewers receive a coal allowance if they are married. In Cumberland no allowances are made.

The hours of labour, or 'shift,' as the working day is technically called, vary under the different scales.

The Somerset, Ocean, and Bedworth scales provide for a minimum wages, and the Somerset scale has also a maximum wages.

The average price of coal is ascertained by accountants pledged to secrecy as to details. In Durham, Cumberland, and Northumberland, the price is the average price at the pit's mouth. In South Wales the price is the price delivered free on board at the port of shipment. This latter price, therefore, evidently includes cost of carriage from the pit to the port—a fact that will explain why the standard price under the South Wales scales is so much higher than the standard prices under the Northern scales. The Somerset scale takes as the price the price delivered at the nearest railway station or wharf.

The advantages of sliding-scales may be reduced to two heads. They give (1) a steadiness to trade, and (2) a steadiness to wages, in so far as disputes between employers and employed tend to render trade and wages unsteady.

The sliding-scale is one more proof that wages are to be regarded as the part of the produce obtained by the labourer, inasmuch as the miner is paid in proportion to the value of the coal raised by him.

Historically, the sliding-scales are connected with supply and demand. The standard wages in most instances are the wages payable at the time the scales were introduced, and the supply of labour as compared with the demand for it was one factor in forming those rates. The scarcity or abundance of labour might lead to a modification of a scale, but this is less likely owing to the spirit of combination that exists in the coal trade.

Legally, the sliding-scale is to be regarded as a part of the contract of service entered into between the mine owner and the miner, prescribing what wages are to be payable during the time such contract continues. Only those persons are bound by a scale who give an express or implied assent to it, and whether such assent has been given in a particular instance would be a question of fact for a jury.

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4. *Anomalies in the condition of Scotch Miners in contrast with other unskilled Labourers.* *By* William Small.

1. All tools requisite for the prosecution of their labour they are compelled to supply, *i.e.*, picks, hammers, shovels, stemmers, drivers, wedges, &c., to the value of from 30*s*. to 40*s*. Other labourers—ploughmen, quarrymen, gardeners, furnacemen, roadsmen, surfacemen, &c.—have all these supplied from capital as part of working plant. Why should miners be compelled to furnish their appliances from the result of labour? The average income of miners is under that earned by any of the foregoing. As a true economic principle, capital should supply all appliances of labour, whatever conventional authority may say to the contrary.

2. When manual power is deficient in intensity to secure success in mining, artificial force is a necessity. Hence powder, dynamite, lime, &c., are in demand. But why should the wage fund of the labourer be compelled to bear the burden? And here the anomalous condition of miners is again shown in bold relief. Are seamen, if unable with oar and sail to propel a vessel, compelled from their wage fund to supply steam; to shape a heavy bar, is a blacksmith called upon to bear the cost of a steam hammer; a quay labourer a steam crane; a quarryman blasting-powder; or a husbandman, unable to thrash all the season's crop with a flail, a steam thrasher? The miners are now beginning to think that capital should supply artificial where manual power is deficient.

3. The miner is compelled to supply himself with light to pursue his occupation because his factory is situated many fathoms underground; but in no other case (generally known) are workmen compelled to illuminate their workshops. The development of electricity as a mine illuminant may ultimately remedy the anomaly, but from conventional precedent employers may charge their workmen for its use.

The perfection of safety-lamps is yearly increasing the miners' outlay, being more costly at purchase and more difficult and expensive to maintain.

4. Royalties are also a source of annoyance, friction, and injustice to the miner; the theory of royalties is meanwhile out of consideration. The case stands thus. A miner may be digging coal at from $7\frac{1}{2}d.$ to $1s.\ 6d.$ per ton—but, for a case, say $10d.$, and the royalty in that seam $1s.\ 4d.$ for a week. The miner earns $20s.$, with deductions $2s.\ 2d.$; nett earning $17s.\ 10d.$, as against $32s.$ to the landlord for royalty. The case is a strong one, but in Lanarkshire the average royalty is $1s.$ per ton. The miners hold that, as formerly and as is still the law of Scotland, such royalty charges should only be exacted by the realm. The idea of forming a 'National Benevolent and Insurance Fund' from such charges is rapidly gaining ground, following the precedent of France, and developing the Knapp Shaft Verein of Germany.

5. The monetary aspect of the foregoing matters is a very serious consideration to working miners, demanding for tools an outlay of $30s.$ to $40s.$; while for weekly charges for oil, powder, sharpening wedges, shafts, &c., they are never under $2s.$ or $2s.\ 6d.$, and thus with the royalty tax and capital exactions their labour is handicapped and natural expansion hindered.

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5. *The Statistics and some points in the Economics of the Scottish Fisheries.* *By* William Watt, *F.S.S.*

The author began by stating that the value of the Scottish fisheries may be roughly estimated at $3\frac{1}{2}$ millions sterling per annum, or $1l.$ per each unit of the population, of which two-thirds are derived from herring. The other sea-fishes yield only three-quarters of a million—haddock producing 300,000$l.$, cod and ling 266,000$l.$ (it might easily be a great deal more); while the yield from whitings, flat-fishes, and the rest is comparatively small. Shellfish reckon in the Fishery Board's statistics for 81,000$l.$, and salmon for 275,000$l.$ The greatest by far, as well as most expansive, of Scottish fishery industries is the 'white cured herring' trade, which in magnitude has more than doubled within the last quarter of a century.

In ten years,	1855–64,	there were cured yearly	625,000 barrels;
„	1865–74	„ „ „	775,000 „
„	1875–84	„ „ „	1,100,000 „
But in the five years,	1880–84,	„ „ „	1,367,000 „
	And last year, 1884,	there were cured	1,700,000 „

The fishermen work at a much greater distance from the land than they did a quarter of a century ago; they have better boats, and a great increase of netting. More than one-half of last year's catch of herrings, namely, 856,000 barrels, was landed within a radius of fifty miles of Aberdeen. Aberdeenshire had 750,000 barrels, equal to an item of 89,000 tons in the general food supply, of which the first price was about eight guineas a ton, or one penny a pound. The same county supplies yearly some 45,000 cattle for conversion into beef, yielding about 15,000 tons, or possibly a little more; worth, with the offal, between $1\frac{1}{4}$ and $1\frac{1}{2}$ million sterling. The entire beef-production of Scotland in a year is about 110,000 tons, and its value, at $75l.$ a ton, $8\frac{1}{4}$ millions; add 70,000 tons of mutton, at $6\frac{3}{4}$ millions, and the animal-food produce of our Scottish fields and pastures is 180,000 tons, and its value 15,000,000$l.$ The produce of the sea, exclusive of shell-fish and salmon, is 275,000 tons, and its value about three millions. In other words, Scotland's contribution of fish to the general food supply is one-third more in quantity and four-fifths less in prime cost than its contribution of beef and mutton.

Eleven-twelfths of last year's herring supply were cured for export, and of the actual exports a still higher proportion went to Germany and Russia. A great change has come over the course of the trade within the last fifty years, as is shown by the following table of exports:—

Year	To Ireland	To the Continent	To places out of Europe
	Barrels	Barrels	Barrels
1834	149,000	56,000	67,000
1859	69,000	203,000	748
1884	35,000	1,149,000	960

The abolition of slavery in the West Indies nearly put an end to the exports of Scotch herrings to 'places out of Europe'; and the potato famine in Ireland led to the introduction of Indian corn and a partial change of dietary there, and to a wholesale exodus of the herring-eating population. We have now only two customers of any importance—Germany and Russia; and it would be more satisfactory if we depended less upon one or two foreign markets. The fishermen number just 50,000, and possess a capital, in boats, nets and lines, of 1,750,000*l.* Those of the north-eastern coast especially are an industrious, saving, and comparatively wealthy class. Many of them are owners of the houses in which they live. They have also substantial sums of money lodged with the banks. Having made some inquiry into this matter, he was enabled, through the courtesy of those connected with banking administration, to state that of the deposit receipts outstanding at twelve branches, in as many of the coast towns, 21 per cent., or more than a fifth of the whole number, are held by fishermen. Their accumulation of savings is thus very considerable, and it is being added to year by year. He might say that one of the branches is almost wholly supported by fishermen. Forty years ago the fishermen of Scotland and the Isle of Man numbered 61,000, and their property in boats, nets, and lines was estimated as worth $1\frac{1}{4}$ million, as compared with $1\frac{3}{4}$ million held by 50,000 Scotch fishermen now. The average value for each man and boy employed was then 20*l.*; it is now 35*l.* So far as the fishermen are concerned, the Scotch herring fishery is a co-operative industry in which capitalists and labourers are united in the same persons. The adoption of steam-power for fishing vessels would save much inconvenience and loss, but would render necessary such an increase in the size and cost of the vessels as would probably to a large extent destroy the pleasant co-operative system at present in vogue.

The system of engagements between curers and fishermen with its accompaniment of a large prepayment months before the fishing begins and irrespective of the quantity caught, was described, and its evils were pointed out. "The brand"—a Government certificate of the quantity and quality of the goods contained in a barrel of cured herrings—was also briefly discussed. It is liked in the trade as facilitating transactions, and being optional and supported by fees, it is not oppressive, while the dependence of the industry upon one or two foreign markets renders its suppression inexpedient. The great need is access to more markets.

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6. *On the Pauperisation of Children by the Operation of the 'Scotch Education Act,* 1872.' *By* MATTHEW BLAIR.

The object of this paper was to set forth some of the evils arising from the operation of the 'Scotch Education Act, 1872,' inasmuch as it compels poor people who have never received 'parochial aid' to pauperise their children.

Section 49 of the Act requires parents who cannot pay for the education of their children to apply to the parochial board, that the fees may be paid out of the poor fund.

Section 70 provides that poor parents who cannot pay their children's fees, and refuse to take poor funds for the purpose, must go to prison for fourteen days.

In the year 1874, the number of the children of non-pauper parents who had their fees paid in part or whole from the poor fund was 2,377, while in 1884 the

number had risen to 15,545, an increase of nearly 700 per cent., the operation of the Act being to undermine the independence of poor Scotchmen.

The remedy suggested is to increase the school rate one-fourth, also to increase the Government grant one-fourth, which would enable Scotch school boards to grant free education up to the fifth standard, at which stage children can leave school.

WEDNESDAY, SEPTEMBER 16.

The following Papers were read:—

1. *Agricultural Investigation and Education.* *By* THOMAS JAMIESON.

Attention was drawn in this paper to the growing tendency to speak of 'Agricultural Science,' a term directly pointing to education in such parts of what is called 'pure science' as can be usefully applied to aid the industry of agriculture. The term 'Agriculture Science' is welcomed as indicating a better realisation of the relation of science to agriculture, but a warning is given against assisting in forming the notion that agriculture is itself a science, and a counsel to keep in view that it is merely an industry intended for money-making, with aims and interests different from those of science, a distinction which in the interest of investigation it is desirable to maintain.

It is also sought in this paper to point out the present defective provision for agricultural education, and that much of the education that is provided is improper in consequence of its consisting of assumed and unproved matter. A practical suggestion is also made bearing both on investigation and education. In regard to agricultural investigation, serious obstacles to its advance are, on the one hand, the unknown or desultory support that is given to it, and on the other hand, the constant reminder that the aim is mercenary, in other words, that those among whom the investigator has to distribute the results of his work have no interest in it beyond its power of seeming to increase pecuniary gain.

The agricultural investigator cannot altogether lose sight of the fact that his researches are carried out with but a sordid money-making object immediately in view; but there is an ultimate object of a higher kind which it is desirable to look to; otherwise evil consequences follow, such as the alienating from the work men who seek knowledge for the sake of knowledge, and who are best fitted for bringing out truths that may aid the industry. It is, therefore, thought important to emphasise and realise this higher aim. To do this one has merely to separate the agriculturist from the ultimate object altogether, and to regard him simply as a means to an end, the end being increased production, more food for all, less need to make life a toil, and hence more leisure to enjoy life. It is perhaps correct to say that, but for the element of discontent, increased production means increased happiness, than which perhaps no higher aim can be held out.

After investigation comes, almost of necessity, education. Agricultural education is properly education in agricultural science; for although some contradiction may seem to be conveyed in adding that agricultural education should consist not only of what is learned in the laboratory or experimental field, but also of facts gained by actual experience or practice on the farm, yet the attendant qualification is important, namely, that neither the one nor the other should be taught from the educational chair till the one has verified the other. On the one hand, the teaching of the laboratory should be confirmed, both on the experimental field and on the farm; on the other hand, the teachings of the farm, should be submitted to the test of the laboratory and experimental field before either should form a part of education. So that, whether the fact has originally been found on the farm or in the laboratory, it would thus pass into the domain of agricultural science, that is to say of proved matter, before it is taught. Agricultural education ought to consist of two parts.

1. The unlearning of what is unsupported by scientific proof, and

2. The learning of what has been fully proved.

In the first branch should be taught the custom to require proof of all that is asserted, and to become acquainted with what constitutes proof. In the second branch the student should go through—

1. The course of the lecture-room, which is best adapted for lucid explanation, but he should be able to go from that place to

2. The Laboratory, in order to confirm what is comprehended, to clear up what he has but hazily understood, and to correct what is erroneous.

3. He should be able to go to an agricultural museum to see the proofs of former trials, illustrations in actual forms, the connection of one part of agriculture to another, and the systems and results of cognate work in other countries.

4. He should have an opportunity of passing to the Experimental Station to realise the application to plants, to see the effect of different seasons, to compare the influence on different plants of the same treatment and the same season, and finally, to learn how to question nature.

It might be added, 'Let him then go to a farm to acquire a knowledge of agricultural practice.' But this is not agricultural education; it is agricultural training, by which he becomes skilled in judging cattle, judging weather, in arranging work, in the drying and storing of crops, &c.; this training is both assisted and forearmed, as it were, by the previous education; by it the student is enabled, that is to say, both to comprehend what practice merely states, without being able to explain, and to perceive errors in practice.

It seems hardly credible that for this, the largest industry of Britain, there are only four places where the desired form of education can be obtained even in a partial way, while none of these places have any State aid. National support is given only in aid of a system of education, which, no doubt, has done much good directly and indirectly, but which partakes of the unproved form of education just alluded to. Now as agricultural investigation should precede education, one might say that the building has been raised by State aid before the foundation has been laid, and, consequently, that the work must become more unstable the longer the system is carried on, and that unless a radical change be made it may be ultimately expected to fall. The work has not yet proceeded so far, perhaps, as to make it yet too late to support it without much interference with the machinery now in action, and perhaps no more useful project could be suggested by which the Secretary of State for Scotland should inaugurate his high post than by being the pioneer in instituting a simple, sensible, well-planned, and not too extensive series of experiments, to be carried out in every county in Scotland under scientific supervision. The results of such a scheme of experiments faithfully recorded, gathered up, and collectively considered by competent persons, would in the course of a few years be, one might say, certainly productive of results of high educational and high national value. Repetitions and extensions of such work would ultimately form the basis of true education that from its very truth would exert its force, and thus might be expected to find its way into the daily practice of agriculture—a circumstance which has not hitherto been attained, probably from the fact that the education has not been based on a proper foundation.

The object of this short paper might be summed up in a few lines. It is intended to draw attention to certain features that probably are tacitly recognised, but are liable to be lost sight of, to the hurt of agriculture, to the hindrance of agricultural investigation, and to loss to the nation.

1. That the aim of agricultural *investigation* is increased knowledge and increased production, and as the latter must benefit the whole nation, this aim should suffice both to ensure national support and to attract and encourage investigators.

2. That the aim of *agriculture* is pecuniary gain to those actually engaged in or having capital engaged in that industry, and that consequently to hinge investigation as a dependent upon it is to expose investigation to a languishing existence or to starvation; for, although the agriculturist, partaking of the rôle of the scientist, may indeed on occasion extend to it sympathy, support, or gratitude, yet it is only when the point has been reached of clearly pointing out a road to gain that as

an agriculturist he can be expected to do his part, namely, of adopting and carrying into practice the results of investigation.

3. That agricultural *education* should be proceeded by and directly based upon agricultural investigation. It should be limited to facts scientifically proved, and should be associated with means of individual verification.

4. That education that does not proceed on this basis, and is not limited to that line, is likely to be pernicious, as likely to perpetuate error.

5. That as Government has undertaken the support of agricultural education, it might be advised to place it on a sure foundation, before it is too late, by instituting a well-considered scheme of agricultural investigation.

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2. *Policy in Taxation.*[1] *By* J. B. Greig.

The circumstances of the time lend emphasis to the demand for reform. As Britain declines to afford adventitious aid, so it is the more bound to avoid interposing adventitious obstacles to the home merchant and producer. Our boasted moderation and caution are apt to degenerate into a hesitant, inconclusive attitude that secures the evils of both competing principles, but the benefit of neither.

The immense gains from a concentrated population are counteracted by a heavy debt, cumbrous officialism, and an immobility of habit, the antithesis of adaptability to circumstances. Budgets are so presented as not to admit of deliberation. While dense population is dependent on manufacturing industry, and that on a low wages rate, which in turn depends on the cost of subsistence, taxes on common articles of diet are still maintained. Coffee and tea are taxed, the former to one-fourth, the latter to the amount of the import cost.

The mode of taxing real property exempts, in effect rewards, those who waste or imperfectly utilise valuable natural agents committed to their care, and provides an inducement to employ movable capital in competition with rather than in aid of native industries.

Barriers are wantonly interposed to men pursuing with free choice certain bread-winning occupations, without any selection by the State of the fittest.

Again, of an obnoxious class are the stamp duties, which make demands on the busy in time, temper, and money, and yield no commensurate gain to the State. In the United States no cheque, receipt, promissory note, transfer disposition, or other document is subject to a revenue stamp; in Britain 151 acts are so burdened, of which 63 are incident to trade, 31 to men following bread-winning occupations.

I do not object to a tax on the profits of trade, but deem a tax on the *operations* at their inception, before it is known if they will result in profit or in loss, most objectionable. In the rudest times, the seed and the tools of the husbandman were passed, and the increase only tithed. On the operations of trade the cheque and receipt stamps bear, and most heavily, on the small trader. The objections urged against existing taxation may be briefly summarised, some imposts being open to our objection, and some objectionable on various grounds.

a. Where the loss to the taxpayer exceeds the gain to the State. The loss is often in the form of inconvenience, unproductive study, delay, and worry.

b. Where the cost of services or commodities is enhanced with the result of prejudicing the home trade in competition.

c. Where the tendency is to discourage the employment of movable capital in this country and to induce its transference to competing countries.

d. Where qualities useful to the State are discouraged, or those injurious to it fostered.

e. Where it arbitrarily restricts the choice of occupation, or the diffusion of trade facilities.

f. Where it induces the use of worse, instead of better, forms of instrument, or the disuse of proper documents and practices.

[1] Published *in extenso* by W. and W. Lindsay, Aberdeen.

g. Where it hinders the ready transfer of property or rights to those most capable of utilising them.

h. Where it ignores the just relations to the State, and *inter se* of taxable subjects, and levies in flagrant disproportion to the benefits conferred.

i. Where it negatives invention in mercantile and financial documents and hinders adaptation to altered circumstances.

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3. *A new view of the Consequences of Unpunctuality in Railway Trains. By* CORNELIUS WALFORD, *F.I.A., F.S.S.*

I do not purpose on this occasion to enter upon any general discussion of railway management, further than to say that for a full generation after the introduction of railway travelling, the most perverse ingenuity appears to have been brought to bear in order to prevent the masses of the people from enjoying its advantages. One of the natural consequences of this policy, beyond direct loss of revenue, seems to have been that when the masses began to travel, in many cases the railways were not in a position, as to terminal accommodation, &c., to convey them with punctuality; not in a position, in fact, to perform the conditions of their own time-tables.

By means of railways, merchants, traders, professional men, clerks, and others having their vocations in cities and towns, are enabled to reside in the suburbs; but this very fact presupposes the existence of facilities of transit to and from these surburban homes to their business locations.

It is only when violent outbursts of complaint arise in the public press from time to time, that we obtain an insight into the method in which these supposed conditions are fulfilled, or rather are systematically disregarded.

It was through the medium of recently published communications—and I shall only rely upon those authenticated with name and address—that I gathered the facts upon which I am about to comment. Persons living within a ten-mile radius of the southern half of the metropolis spoke of from ten to twenty-five minutes' delay in performing the journey either way as a chronic state of irregularity.

No doubt the landing of tens of thousands of persons daily between the hours of 8.30 and 10.30 a.m., and conveying these away again between the hours of 4 and 6 p.m., is attended with enormous practical difficulties. But the railway companies undertake to do it, and readily enter into contracts to that end.

On the strength of these assurances people remove their homes into the country, and build or buy houses, or enter into rental engagements extending over terms of years. In doing so under the present state of things, other perils than those involved in such financial engagements await them. These it is the especial object of this paper to comment upon.

I will take for my particular text the case of a systematic delay of fifteen minutes on the journey each way—by no means a maximum instance of delay. *That* involves in the six working days of the week a loss of three hours of direct time, amounting in the year of 50 working weeks to 150 hours; equal to 25 ordinary business days of six hours, *or about equivalent to one-twelfth of the city working year.*

This is as applied to one individual. But take the average number of passengers in each of these city trains at 300—rather below than above the number carried on many lines—and see what the accumulated results in wasted time reaches. Then again, multiply this total by the two or three hundred trains running daily into London alone, and the aggregate waste of time can be readily computed into figures almost astounding.

Now if it were simply a matter of waste of time, that could in some degree be taken into account and allowed for in estimating the advantages of a country as against a town residence; but the greater evils of these constantly-recurring delays show themselves in other forms. There is the mental anxiety of the morning in knowing that the business of the day is being thrown back by

every unnecessary minute's delay of the journey, and a consequent struggle on the part of the principals and staff during the day to overtake the time so lost in the journey. In the afternoon the jaded powers are again placed under irritating influences; the garden exercise before dinner shorn of its proportions or altogether lost, or the evening meal delayed or hurried, with corresponding injury to the system. When I hear of men giving up country residence after a few years' trial, on the plea perhaps that railway travelling daily does not suit them, I wonder how much of the trouble arises from these conditions of unpunctual time-keeping and its concomitant mischiefs.

I have not desired in this short paper in any way to overstate the case as against the railway companies. No good end would be served thereby. The question is one capable of some elucidation by every one concerned. It may be that it will be found by railway companies that the purely surburban traffic does not pay—does not or will not pay for the terminal expenditure necessary to render the stations of our great cities equal to the stress entailed during certain hours of the day. If this be so it had better be known, and the tramways—when the ignorance of vestries and local boards shall be overcome—may be found equal to the emergency.

I commend some of the reflections here offered to the careful consideration of our friends of the medical faculty. For some years I travelled about eighty miles a day up and down to business by trains that were reasonably punctual, and found my health benefited rather than otherwise by the repose of the journey.

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4. *On the Industrial Remuneration Conference.* *By the* Rev. W. Cunningham, *B.D.*

This Conference was organised under the auspices of the Statistical Society to carry out the wishes of an Edinburgh gentleman, who had devoted 1,000*l.* to the purpose of discussing how far the existing system for the distribution of the products of industry was satisfactory, and how far capable of improvement. Many practical suggestions of importance had been thrown out, but it was hardly worth while to commence a discussion of them in detail. It was more desirable to try and understand how a representative Conference of this kind regarded the studies to which Section F was devoted. While there was a very general wish that the Government should collect and publish statistics of wages and prices, this was sought for purely practical purposes, and was no evidence of interest in statistical science. This was further illustrated by the attitude assumed towards statistical inquiries about the progress of the working classes. There was evidently a strong feeling among artisans that the recent inquiries were inaccurate, as no sufficient account was taken of the intensity of labour, or of the irregularity of employment. Besides being inaccurate, the inquiries seemed to many to be irrelevant; they dealt with the individual as isolated, while many wanted to estimate the improvement in the lot of the labourer relatively to the progress of society, and held that when the question was put in this form, there had been no progress among the working classes, and that the attempts to measure it were worse than useless. The discussions at the Conference also showed that economic science was little appreciated, and much remained to be done before the public could be convinced that there is such a science, or cultivated men could be found to agree as to its nature. The Conference also proved that the land agitation had a wider hold than might have been expected, and gave indications of a similar agitation in the immediate future against credit and banking which might be very much more difficult to oppose.

SECTION G.—MECHANICAL SCIENCE.

PRESIDENT OF THE SECTION—B. BAKER, M.Inst.C.E.

THURSDAY, SEPTEMBER 10.

The PRESIDENT delivered the following Address:—

GENTLEMEN,—Two hundred and fifty-seven Presidential Addresses of one kind and another have been delivered at meetings of the British Association since the members last mustered at Aberdeen. I need hardly say that the candid friend who informed me of this interesting fact most effectually dispelled any illusion I may have previously entertained as to the possibility of preparing an address of sufficient novelty and suggestiveness to be worthy of your attention, and I can only hope that any shortcomings will be dealt with leniently by you. One compensating advantage obviously belongs to my late appearance in the field—I have two hundred and fifty-seven models of style upon which to frame my address. My distinguished predecessor, Sir Frederick Bramwell, has a style of his own, in which wit and wisdom are combined in palatable proportions; but were I to attempt this style I should doubtless incur the rebuke which a dramatic critic of Charles the Second's time administered to a too ambitious imitator of a popular favourite: 'He's got his fiddle, but not his hands to play on't.' I must search further back than last year, therefore, for a model of style, and the search reminds me that I labour under a double disadvantage: firstly, that only two addresses intervene between the present one and that of my partner, Mr. John Fowler, with whom I have so long had the honour of being associated, and whose professional experiences, as set forth in his address, are necessarily so largely identical with my own; and, secondly, that within the same period I have read before this Section two somewhat lengthy papers on the work which is at present chiefly engaging the attention of Mr. Fowler and myself—the great Forth bridge.

Although, for the reasons aforesaid, I am conscious that my address may fail in novelty, I cannot honestly profess to feel a difficulty in preparing an address of some kind, for the subjects embraced under the head of 'Mechanical Science' are so inexhaustible that even the youngest student might safely accept the responsibility of speaking for an hour on some of them. Professor Rankine, addressing you thirty years ago, said it was well understood that questions of pure or abstract mechanics form no part of the subjects dealt with in this Section. With characteristic clearness of conception and precision of language, he told you what the term 'Mechanical Science' meant, and, after thirty years' interval, his words may be recalled with advantage to everyone proposing to prepare an address or report for this Section. 'Mechanical Science,' said Professor Rankine, 'enables its possessor to plan a structure or machine for a given purpose without the necessity of copying some existent example; to compute the theoretical limit of the strength and stability of a structure or the efficiency of a machine of a particular kind; to ascertain how far an actual structure or machine fails to attain that limit, and to discover the cause and the remedy of such shortcoming; to determine to what extent, in laying down principles for practical use, it is advantageous for the sake of simplicity to deviate from the exactness required by pure science; and to judge

how far an existing practical rule is founded on reason, how far on custom, and how far on error.' There is thus an ample text for many discourses; but, as I am not writing a treatise on engineering, but merely delivering a brief address, I will confine my attention at present to a particular case of the branch of mechanical science referred to in the last clause of Professor Rankine's definition, and will ask you to consider how far the existing practical rules respecting the strength of metallic bridges are 'founded on reason, how far on custom, and how far on error.'

The first question obviously is, What are the rules adopted by engineers and Government departments at the present time?—and it is one not easily answered. I have for some time past been receiving communications from leading Continental and American engineers, asking me what is my practice as regards the admissible intensity of stress on iron and steel bridges, and in replying I have invited similar communications from themselves. As a result, I am able to say that at the present time absolute chaos prevails. The old foundations are shaken, and engineers have not come to any agreement respecting the rebuilding of the structure. The variance in the strength of existing bridges is such as to be apparent to the educated eye without any calculation. If the wheels of a miniature brougham were fitted to a heavy cart, the incident would excite the derision even of our street boys, and yet equal want of reason and method is to be found in hundreds of bridges in all countries. It is an open secret that nearly all the large railway companies are strengthening their bridges, and necessarily so, for I could cite cases where the working stress on the iron has exceeded by 250 per cent. that considered admissible by leading American and German bridge builders in similar structures.

In the case of old bridges the variance in strength is often partly due to errors in hypothesis and miscalculation of stresses. In the present day engineers of all countries are in accord as to the principles of estimating the magnitude of the stresses on the different members of a structure, but not so in proportioning the members to resist those stresses. The practical result is that a bridge which would be passed by the English Board of Trade would require to be strengthened 5 per cent. in some parts and 60 per cent. in others before it would be accepted by the German Government or by any of the leading railway companies in America. This undesirable state of affairs arises from the fact that in our own and some other countries many engineers still persistently ignore the fact that a bar of iron may be broken in two ways—namely, by the single application of a heavy stress or by the repeated application of a comparatively light stress. An athlete's muscles have often been likened to a bar of iron, but, if 'fatigue' be in question, the simile is very wide of the truth. Intermittent action—the alternative pull and thrust of the rower, or of the labourer turning a winch—is what the muscle likes and the bar of iron abhors. Troopers dismount to rest their horses, but to relieve a bar of iron temporarily of load only serves to fatigue it. Half a century ago Braithwaite correctly attributed the failure of some girders, carrying a large brewery vat, to the vessel being sometimes full and sometimes empty, the repeated deflection, although imperceptibly slow and wholly free from vibration, deteriorating the metal, until, in the course of years, the girders broke. These girders were of cast iron; but it was equally well known that wrought iron was similarly affected, for in 1842 Nasmyth called the attention of this Section to the fact that the 'alternate strain' in axles rendered them weak and brittle, and suggested annealing as a remedy, he having found that an axle which would snap with one blow when worn would bear eighteen blows when new or after being annealed.

So important a matter as the action of intermittent stresses could not escape the attention of the Royal Commissioners appointed in 1849 to consider the application of iron to railway structures, and some significant and sufficiently conclusive experiments were made by Captain Douglas Galton and others. Cast-iron bars 3 inches square and 13 feet 6 inches span between the supports were deflected, both by the slow action of a cam and the percussive action of a swinging pendulum weight. When the deflection was that due to one-third of the breaking weight, about 50,000 successive bendings by the cam broke one of the bars, and about 1,000 blows from the pendulum another. When the deflection was increased from one-third to one-half, about 500 applications of the cam, and 100 blows,

sufficed to rupture two of the specimens. Slow-moving weights on bars and on a small wrought-iron box girder gave analogous results; and the deduction drawn by the experimenters at the time was that 'iron bars scarcely bear the reiterated application of one-third the breaking weight without injury, hence the prudence of always making beams capable of bearing six times the greatest weight that could be laid upon them.'

Although these experiments were entirely confirmatory of all previous experience, they would appear to have little influenced the practice of engineers, since Fairbairn, more than ten years later, in a communication to this Section, said that opinions were still much divided upon the question whether the continuous change of load which many wrought-iron structures undergo has any permanent effect upon their ultimate powers of resistance. To assist in settling the question he communicated to the Association the results of some experiments carried out by himself and Professor Unwin on a little riveted girder 20 feet span and 16 inches deep. Once more the same important but disregarded facts were enforced on the attention of engineers. About 5,000 applications of a load equal to four-tenths of the calculated breaking load fractured the beam with the small ultimate deflection of three-eighths of an inch, and subsequently, when repaired, the beam broke with one-third of the load and a deflection of but a quarter of an inch, which sufficiently indicated how small a margin the factor of safety of four, then currently adopted, allowed for defective manufacture, inferior material, and errors in calculation. Still nothing was done, and the general practice of engineers and the Board of Trade regulations continued unaltered.

Soon after the introduction of wrought-iron bridges on railways, the testimony of practical working was added to that of experiments. In 1848 several girder bridges of unduly light proportions were erected in America, and one of 66 feet span broke down under the action of the rolling load in the same manner as Fairbairn's little experimental girder. Again, in early American timber bridges the vertical tie-rods were often subject to stresses oscillating between one ton and ten tons per square inch and upwards. Many of these broke, as did also the suspension bolts in platforms subjected to similar stresses. In my own experience, dozens of broken flange-plates and angle-bars, and hundreds of sheared rivets, have been the silent witnesses of the destructive action of a live load. Like evidence was afforded by early-constructed iron ships deficient in girder strength. Under the alternating stresses due to the action of the waves weaknesses not at first apparent would, in the course of time, be developed, and additional strength, in the way of stringers and otherwise, become imperative.

If none of the preceding evidence had been forthcoming, the results of the historical series of experiments carried out by Wöhler for the Prussian Ministry of Commerce would alone be conclusive. For the first time a truly scientific method of investigation was followed, and an attempt was made to determine the laws governing the already proved destructive action of intermittent stresses. In previous experiments the bar or girder was alternately fully loaded and wholly relieved of load. Wöhler was not satisfied with this, but tested also the result of a partial relief of load. The striking fact was soon evidenced, on testing specimens under varying tensions, that the amount of the variation was as necessary to be considered as that of the maximum stress. Thus, an iron bar having a tensile strength of 24 tons per square inch broke with about 100,000 applications of a stress varying from *nil* to 21 tons, but resisted 4,000,000 applications of the 21 tons when the minimum stress was varied from *nil* to $11\frac{1}{2}$ tons. The alternations of stress in the case of some test pieces numbered no less than 132,000,000; and too much credit cannot be bestowed by engineers upon Wöhler for the ingenuity and patience which characterised his researches. As a result, it is proved beyond all further question that any bar or beam of cast iron, wrought iron, or steel may be fractured by the continued repetition of comparatively small stresses, and that, as the differences of stress increase, the maximum stress capable of being sustained diminishes.

Various formulæ based upon the preceding experiments have been proposed for the determination of the proper sectional area of the members of metallic structures. These formulæ differ in some essential respects, and doubtless many experiments

are still required before any universally accepted rules can be laid down. Probably at the present time the engineers who have given the most attention to the subject are fairly in accord in holding that the admissible stress per square inch in a wrought-iron girder subject to a steady dead load would be one and a half times as great as that in a girder subject to a wholly live load, and three times that allowable in members subject to alternate tensile and compressive stresses of equal intensity, such as the piston-rod of a steam-engine or the central web bracing of a lattice girder. If the alternations of stress to be guarded against are not assumably infinite in number, but only occasional—as in wind bracing for hurricane pressures, or in a vessel amongst exceptionally high waves—then the aforesaid ratio of 3, 2, and 1 would not apply, but would more nearly approach the ratios 6, 5, and 4.

Hundreds of existing railway bridges, which carry twenty trains a day with perfect safety, would break down quickly under twenty trains per hour. This fact was forced on my attention nearly twenty years ago by the fracture of a number of iron girders of ordinary strength under a five-minute train service. Similarly, when in New York last year I noticed, in the case of some hundreds of girders on the 'Elevated Railway,' that the alternate thrust and pull on the central diagonals from trains passing every two or three minutes had developed weaknesses which necessitated the bars being replaced by stronger ones after a very short service. Somewhat the same thing had to be done recently in this country with a bridge over the Trent, but the train service being small the life of the bars was measured by years instead of months. If ships were always amongst great waves the number going to the bottom would be largely increased, for, according to Mr. John, late of Lloyd's, 'many large merchant steamers afloat are so deficient in longitudinal strength that they are liable under certain conditions of sea to be strained in the upper works to a tension of from 8 to 9 tons per square inch, and to a compression of from 6 to 7 tons'—stresses which the experiments already referred to prove would cause failure after a definite number of repetitions. Similarly, on taking ground or being dry-docked with a heavy cargo on board, it has been shown that vessels are liable to stresses of over 11 tons per square inch on the reverse frames, but no permanent injury results from such high stresses, because the number of repetitions is necessarily very limited.

It appears natural enough to everyone that a piece even of the toughest wire should be quickly broken if bent backward and forward to a sharp angle; but, perhaps, only to locomotive and marine engineers does it appear equally natural that the same result would follow in time if the bending were so small as to be quite imperceptible to the eye. A locomotive crank axle bends but $\frac{1}{34}$ in., and a straight driving axle the still smaller amount of $\frac{1}{64}$ in., under the heaviest bending stresses to which they are subject, and yet their life is limited. During the year 1883 one iron axle in fifty broke in running, and one in fifteen was renewed in consequence of defects. Taking iron and steel axles together, the number then in use on the railways of the United Kingdom was 14,848, and of these, 911 required renewal during the year. Similarly, during the past three years no less than 228 ocean steamers were disabled by broken shafts, the average safe life of which is said to be about three or four years. In other words, experience has proved that a very moderate stress alternating from tension to compression, if repeated about one hundred million times, will cause fracture as surely as a sharp bending to an angle repeated perhaps only ten times.

I have myself made many experiments with a view to elucidate the laws affecting the strength of iron- and steel-work subject to frequent alternations of stress. Perhaps the most suggestive series was one in which I subjected flat steel bars about three feet long, in pairs, to repeated bendings until one bar broke, and then testing the surviving bar under direct tensile and compression stresses to ascertain to what extent the metal had deteriorated. It had come under my notice, as a practical engineer, that if the compression members of a structure were unduly weak the fact became quickly evident, perhaps under the test load; but if, on the other hand, the tension members were weak, no evidence might appear of the fact until frequent repetition of stresses during several years had caused them

to fracture without any measurable elongation of the metal. In the case of crank-shafts, also, the fracture is invariably due to a tearing and not a crushing action. It appeared to me, therefore, eminently probably that repetition of stresses might be far more prejudicial to tension than to compression members, and, if so, the fact ought to be taken account of in proportioning a structure.

This proved to be the case in my experiments. For example, the companion bars to those which had broken with 18,000 reversals of a stress less than half the original breaking weight behaved, when tested as columns thirty diameters in length, precisely the same as similar bars which had done no work at all, whereas when tested in tension the elongation was reduced from the original 25 per cent. to 2·5 per cent., and the fracture appeared to indicate that the bars had been made of three different kinds of steel imperfectly welded together. With a stress reduced by one-fourth the number of bendings required to break the bars was increased to 1,200,000. In this instance the calculated maximum working stress on the extreme fibres was 43 per cent. of the direct ultimate tensile resistance of the steel, and about 30 per cent. of the stress the bar was capable of sustaining as a beam under the single application of a load. Of course, the bars failed by tension, and the extreme fibres had thus deteriorated as regards tensile stresses to the extent indicated by the above percentages. Tested as a column, however, the injury the bar had received from the 1,200,000 bendings was inappreciable. The ductility was of course very largely reduced, but ductility is a quality of comparatively little importance when a material is in compression. There is no ductility in the slender Gothic stone columns of our cathedrals, which, though heavily stressed, have carried their loads for centuries. As I found repeated bendings raised the limit of elasticity, I rather anticipated finding an increased resistance from this cause in long columns. This did not prove to be the case, nor did I find any difference in short columns four diameters in length.

In addition to the preceding experiments with rectangular bars, I have tested the endurance of many revolving shafts of cast iron, wrought iron, and steel, with similar results. About 5,000 reversals of a stress equal to one-half the static breaking weight sufficed generally to cause the snapping of a shaft of any of the above materials. When the stress was reduced and the number of applications increased, I found the relative endurance of solid beams to be more nearly proportional to the tensile strength of the metal than to the breaking weight of the beam, a distinction of great importance where axles, springs, and similar things are concerned. Many of my experiments were singularly suggestive. Thus, it was instructive to see a bar of cast iron loaded with a weight which, according to Fairbairn's experiments, it should have carried for a long series of years, broken in two minutes when set gently rotating. Also to find a bar of the finest mild steel so changed in constitution by some months of rotation as to offer no advantages either in strength or toughness over a new cast-iron bar of the same section.

Although, as already stated, many more experiments are required before universally acceptable rules can be laid down, I have thoroughly convinced myself that, where stresses of varying intensity occur, tension and compression members should be treated on an entirely different basis. If, in the case of a tension member, the sectional area be increased 50 per cent. because the stress, instead of being constant, ranges from *nil* to the maximum, then I think 20 per cent. increase would be a liberal allowance in the case of a compression member. I have also satisfied myself that if a metallic railway bridge is to be built at a minimum first cost, and be free from all future charges for structural maintenance, it is essential to vary the working stress upon the metal within very wide limits, regard being had not merely to the effect of intermittent stresses, but also to the relative limits of elasticity in tension and compression members even under a steady load.

Why an originally strong and ductile metal should become weak and brittle under the frequent repetition of a moderate stress has not yet been explained. Lord Bacon touched upon the subject two or three centuries ago, but you may consider his explanation not wholly satisfactory. He said, 'Of bodies, some are fragile, and some are tough and not fragile. Of fragility, the cause is an impotency to be extended, and the cause of this inaptness is the small quantity of spirits.' I

am sorry to have no better explanation to offer, but whatever may be the immediate cause of fragility, no doubt exists that it is induced in metals by frequent bendings, such as a railway bridge undergoes. This fact, however, is not recognised in our Board of Trade regulations, which remain as they were in the dark ages, as do those of the Ministry of Public Works of France and other countries. With us it is simply provided that the stress on an iron bridge must not exceed 5 tons per square inch on the effective section of the metal. In France it is still worse, as the limiting stress of rather under 4 tons per square inch is estimated upon the gross section, regardless of the extent to which the plates may be perforated by rivet holes. In neither case is any regard had in the rules to intermittent stresses or the flexure of compression members. In Austria the regulations make a small provision for these elements; and American specifications make a large one, the limiting stresses, instead of being constant at 5 tons, as with us, ranging from about $2\frac{1}{2}$ tons to $6\frac{3}{4}$ tons per square inch, according to circumstances. It is hardly necessary that I should say more to justify my statement that, as regards the admissible intensity of stress on metallic bridges, absolute chaos prevails.

Engineers must remember that if satisfactory rules are to be framed, they, and not Governmental departments, must take the initiative. In former days the British Association did much to direct the attention of engineers to this important matter, but, so far as I know, the subject has been dropped for the past twenty years, and I have ventured, therefore, to bring it before you again in some detail. We are here avowedly for the advancement of science, and I have not been deterred by the dryness of the subject from soliciting your attention to a branch of science which is sadly in need of advancement.

Had I been addressing a less scientific audience, I might have been tempted rather to boast of the achievements of engineers than to point out their shortcomings. The progress in many branches of mechanical science during the past fifty years has exceeded the anticipation of the most far-seeing. Fifty years ago the chairman of the Stockton and Darlington Railway, when asked by a Parliamentary committee if he thought any further improvements would be possible on railways, replied that he understood in future all new railways would have a high earthwork bank on each side to prevent engines toppling over the embankments and to arrest hot ashes, which continually set fire to neighbouring stacks, but in other respects he appeared to think perfection was attained. Shortly before the introduction of locomotives it was also thought perfection was attained when low trucks were attached to the trains to carry the horses over the portions of the line where descending grades prevailed, and all the newspapers announced, with a great flourish of trumpets, that a year's experience showed the saving in horseflesh to be fully 33 per cent.

Although these views seem childlike enough from our present standpoint, I have no doubt that as able and enterprising engineers existed prior to the age of steam and steel as exist now, and their work was as beneficial to mankind, though different in direction. In the important matter of water supply to towns, indeed, I doubt whether, having reference to facility of execution, even greater works were not done 2,000 years ago than now. Herodotus speaks of a tunnel 8 ft. square, and nearly a mile long, driven through a mountain in order to supply the city of Samos with water; and his statement, though long doubted, was verified in 1882 through the abbot of a neighbouring cloister accidentally unearthing some stone slabs. The German Archæological Society sent out Ernst Fabricius to make a complete survey of the work and the record reads like that of a modern engineering undertaking. Thus, from a covered reservoir in the hills proceeded an arched conduit about 1,000 yards long, partly driven as a tunnel and partly executed on the 'cut and cover' system adopted on the London underground railway. The tunnel proper, more than 1,100 yards in length, was hewn by hammer and chisel through the solid limestone rock. It was driven from the two ends like the great Alpine tunnels, without intermediate shafts, and the engineers of 2,400 years ago might well be congratulated for getting only some dozen feet out of level and little more out of line. From the lower end of the tunnel branches were constructed to supply the city mains and fountains, and the explorers found ventilating shafts and

side entrances, earthenware socket pipes with cement joints, and other interesting details connected with the water supply of towns.

In the matter of masonry bridges, also, as great works were undertaken some centuries ago as in recent times. Sir John Rennie stated, in his presidential address at the Institution of Civil Engineers, that the bridge across the Dee at Chester was the 'largest stone arch on record.' That is not so. The Dee bridge consists of a single segmental arch 200 ft. span and 42 ft. rise; but across the Adda, in Northern Italy, was built, in the year 1377—more than 500 years ago—a similar segmental arch bridge of no less than 237 ft. span and 68 ft. rise. Ferrario not long since published an account of this, for the period, colossal work, from which it would appear that its life was but 39 years, the bridge having been destroyed for military reasons on December 21, 1416. I believe our American cousins claim to have built the biggest existing stone arch bridge in the world, that across the Cabin Johns Creek, but the span, after all, is only 215 ft., or ten per cent. smaller than the 500-year-old bridge. In timber bridges, doubtless, the Americans will ever head the list, for the bridge of 340 ft. span built across the Schuylkill three-quarters of a century ago will probably never be surpassed. Our ancestors were splendid workers in stone and timber, and, if they had been in possession of an unlimited supply of iron and steel, I fear there would have been little left for modern bridge builders to originate.

The labours of the present generation of engineers are lightened beyond all estimate by labour-saving appliances. To prove how much the world is indebted to students of this branch of mechanical science, and how rapid is the development of a really good mechanical notion, it is only necessary to refer to the numerous hydraulic appliances of the kind first introduced forty years ago by a distinguished past-President, Sir W. G. Armstrong. Addressing you in 1854, Sir William Armstrong explained that the object he had in view from the first was 'to provide, in substitution of manual labour, a method of working a multiplicity of machines, intermittent in their action and extending over a large area, by means of transmitted power, produced by a steam-engine and accumulated at one central point.' The number of cases in which this method of working is a desideratum, or even indispensable, would appear to be limitless. I should be sorry indeed to have anything to do with building the Forth bridge if hydraulic appliances were not at hand to do a giant's work. Let me shortly describe to you what we are doing there at the present time. More than 42,000 tons of steel plates and bars have to be bent, planed, drilled, and riveted together before or after erection, and hydraulic appliances are used throughout. The plates are handled in the shops by numerous little hydraulic cranes of special design, without any complication of multiplying sheaves, the whole arm being raised with the load by a 4-in. direct-acting ram of 6 ft. stroke. A total length of no less than 60 miles of steel plates, ranging in thickness from $1\frac{1}{4}$ in. to $\frac{5}{8}$ in., have to be bent to radii of from 6 ft. to 9 in., which is done in heavy cast-iron dies squeezed together by four rams of 24 in. in diameter, and the same stroke. With the ordinary working pressure of 1,000 lbs. per square inch, the power of the press is thus about 1,750 tons. Some 3,000 pieces, shaped like the lid of a box, 15 in. by 12 in. wide, with a 3-in. deep rim all round, were required to be made of $\frac{1}{2}$-in. steel plate, and this was easily effected in two heats by a couple of strokes of a 14-in. ram. In numberless other instances steady hydraulic pressure has been substituted by Mr. Arrol, our able contractor, for the usual cutting and welding under the blacksmith's hammer.

Hydraulic appliances are also an indispensable part of the scheme for erecting the great 1,700 ft. spans. Massive girders will be put together at a low level, and be hoisted as high as the top of St. Paul's Cathedral by hydraulic power. Continuous girders, nearly a third of a mile in length, will be similarly raised. Not only the girders, but workmen, their sheds, cranes, and appliances, will be carried up steadily and imperceptibly as the work of erection proceeds, on platforms weighing in some instances more than 1,000 tons. It is hardly necessary to say that every rivet in the bridge will be closed up by hydraulic power, the machines being in many instances of novel design, specially adapted to the work. Thus the bed-plates, which in ordinary bridges are simple castings, in the Forth

bridge are necessarily built up of numerous steel plates, the size of each bed-plate being 37 ft. long by 17 ft. 6 in. wide. To grip together the 47 separate plates into a solid mass 3,800 rivets 1¼ in. in diameter with countersunk heads on both sides are required, and, remembering that the least dimension of the bed-plate is 17 ft. 6 in., it will be seen the ordinary 'gap'-riveter would not be applicable. A special machine was therefore designed by Mr. Arrol, consisting of a pair of girders and a pair of rams, between which the bed-plate to be riveted together lies. A double ram machine had for like reasons to be devised for riveting up the great tubular struts of the bridge.

Not merely in the superstructure, but in the construction of the foundations, were hydraulic appliances of a novel character indispensable at the Forth bridge. Huge wrought-iron caissons or cylinders, 70 ft. diameter and 72 ft. high, were taken up and set down as readily as a man would handle a bucket. In sinking these caissons through the mud and clay of the Forth compressed air was used. When the boulder clay was reached the labour of excavating the extremely hard and tenacious material in the compressed air-chamber proved too exhausting, pickaxes were of little avail, and the Italian labourers who were chiefly employed lost heart over the job altogether. But a giant power was at hand, and only required tools fit for the work. Spades with hydraulic rams in the hollow handles were made, and, with the roof of the compressed air-chamber to thrust against, the workmen had merely to hold the handle vertically, turn a little tap, and down went the spade with a force of three tons into the hitherto impracticable clay as sweetly as a knife into butter. Probably, when addressing you thirty years ago, Sir William Armstrong never anticipated that a number of hydraulic spades would be digging away in an electrically lighted chamber or diving bell, 70 ft. diameter and 7 ft. high, 90 ft. below the waves of the sea; but still the spades come strictly within the definition of the class of machines, intermittent in their action and extending over a large area, which it was his aim to introduce. It would be possible, indeed, with the appliances at the Forth bridge, to arrange that the simple opening of a valve should start digging at the bottom of the sea, riveting at a height of nearly 400 ft. above the sea, and all the multifarious operations of bending, forging, and hoisting, extending over a site a mile and a half in length.

It would not only be impossible to build a Forth bridge, but it would be equally impossible to fight a modern ironclad without the aid of hydraulic appliances. Most of the Presidents of this Section have referred in the course of their addresses to our Navy, and certainly the subject is a tempting one, for the progress of mechanical science in recent years could not be better illustrated than by a description of the innumerable appliances which go to the making and working of a modern ironclad. Let me quote a single passage from a pamphlet by a naval officer, which caused a great stir a few years before the Crimean war, that I may recall to your minds what was the speed and what the armament of our fleet at that comparatively recent period. 'Conceive,' said Captain Plunkett, R.N., 'a British and French fleet issuing simultaneously from Spithead and Cherbourg; seven hours' steaming at the rate of six miles an hour will bring them together. A single glance at the heavy and well-appointed tiers of a line-of-battle ship's guns will satisfy anyone that they are no toys to be placed in the hands of novices. Formidable batteries of the heaviest ordnance are there—not a gun under a 32-pounder, and many 68-pounder shell guns.' In little more than a quarter of a century engineers have changed all that, and advanced to 20-knot vessels and 120-ton guns. Archæologists tell us that our predecessors in mechanical science, of the Stone Age, were apparently a thousand or more years in finding out that the best way of fitting an axe was to slip the handle through the axe and not the axe through the handle. Engineers of the present day may be excused, therefore, for occasionally illustrating the rapidity of the advance of their science by contrasting the ships of thirty years ago with our modern ironclads.

The latest type of battle-ship weighs, fully equipped, about 10,000 tons. There are about 3,400 tons of steel in her hull, apart from armour, which with its backing will weigh a further 2,800 tons. The machinery, largely of steel, is about 1,400 tons; the armament, including ammunition, 1,100 tons; the coals, 1,100 tons; and

general equipment, 270 tons. A detailed description bristles with the word 'steel,' and enthusiastic newspaper reporters sent down to Chatham Dockyard can no more 'spin out their copy' with Cowper's oft-quoted lines on the 'Launch of a First-Rate:'—

'Giant oaks of bold expansion
O'er seven hundred acres fell,
All to build thy noble mansion,
Where our hearts of oak do dwell.'

A latter-day poet might boast of 700 acres being exhausted by a single vessel, but it would be a coal-field and not a forest. Accepting Professor Phillips's estimate of the average rate of formation of coal, it may be shown that a hard-worked American liner during her lifetime burns as much coal as would be produced on the area of 700 acres in a period of 2,000 years. We are thus with our steel ships using up our primeval forests at a far more extravagant rate than that at which our immediate forefathers cleared the oak forests. Coal is the great stimulant of the modern engineer. Pope Pius the Second has left on record an expression of the astonishment he felt when visiting Scotland, in the fifteenth century, on seeing poor people in rags begging at church doors, and receiving for alms pieces of black stone, with which they went away contented. To such early familiarity with coal may, however, be due the fact that Scotland has ever led the way in the development of the steam-engine, and that at the date of the battle of Waterloo she had built and registered seven steam vessels, whilst England could boast of none.

Probably none but a poet or a painter would wish for a return to our old oak sailing ships. Some few people still entertain the illusion that the picturesque old tubs were better sea boats than our razor-ended steamers; but, speaking of them in 1846, Admiral Napier said, 'The ships look very charmingly in harbour, but to judge of them properly you should see them in a gale of wind, when it would be found they would roll 45° leeward and 43° windward.' Even our first ironclads were not so bad as that, for although, according to the *Times*, when the squadron was on trial in the Bay of Biscay, the ships rocked wildly to the rising swell and the sea broke in great hills of surf, yet the maximum roll signalled by the worst roller of the lot—the 'Lord Warden'—was but 35° leeward and 27° windward—a total range of 62°, as compared with 88° in the old line-of-battle ships.

We have heard much about the state of the Navy during the past twelve months. A dip into the publications of the British Association—which in this, as in other respects, afford a fair indication of what is uppermost in people's minds—will show that similar discussions have recurred periodically, at any rate, since 1830. If we consult Hansard, as I had occasion to do recently, we find the same remark applies to periods long antecedent to 1830.

It amounts almost to a religious conviction in the mind of a Briton that Providence will not be on his side unless his fleet is at least equal to that of France and Russia united. What would be said now of a minister who met an attack on the administration of the Navy by demonstrating that we had *half* as many line-of-battle ships as Russia; and yet that was literally done less than 50 years ago. Speaking in the House of Commons, on March 4, 1839, the Secretary of the Admiralty said: 'For the last six months unceasing attacks have been made upon our naval administration, describing our Navy as in a state of the utmost decrepitude, and Tory papers say that shameful reductions have been made in the Navy by the present Government. It will be a consolation to my honourable friends to be assured that we have for years lived unharmed through dangers as great as that to which we are now exposed. In 1817 we had 15 sail of the line in commission, and Russia had 30; in 1823 we had 12, and Russia 37; in 1832 we had 11, and Russia 36; and now we have 20, and the Russians 43, having raised our ships to nearly half the number of those of Russia.'

Now as to our guns. The past twelve months is by no means the first occasion on which the armament of our Navy has been attacked. Three years subsequent to the speech of the Secretary of the Admiralty just referred to, Sir Charles Napier made a statement from his place in Parliament of so extraordinary a character that

I make no apology for quoting his exact words, as a reminder of the past and a warning for the future: 'At the end of the last war the guns were in such a bad state that, when fired, they would scarcely hit an enemy, and during the latter period of the American war a secret order was issued that British ships of war should not engage American frigates, because the former were in such an inefficient state.' As for himself, said the plain-spoken old admiral, when he got the order he put it in 'the only place fit to receive it, the quarter-gallery.'

Happily, from our insular position, the change which the progress of mechanical science has wrought in military operations has not been brought home to the people of this country in the same vivid manner that it has to the people of the continents of Europe and America. In the American war, the Franco-German war, and the Russo-Turkish war the construction and equipment of railway works by engineers was an essential part of all great movements. The Russians, in 1877, constructed a railway from Bender to Galatz, 189 miles in length, in 58 working days, or at the rate of more than three miles per day. Altogether, in the three latter months of that year they laid out and built about 240 miles of railway, and purchased and stocked the line with 110 locomotives and 2,200 wagons. They also built numerous trestle bridges, together with an opening bridge and a ferry across the Danube.

We have had recent experiences of the slowness of primitive modes of transport in the tedious advance of Lord Wolseley's handful of men in whale-boats up the Nile. It was the intention of the late Khedive, partly from military and partly from commercial considerations, to construct a railway exactly on the line of advance subsequently followed by Wolseley. My partner, Mr. Fowler, had the railway set out in 1873, and the works were shortly after commenced. The total length was 550 miles, and the estimated cost, including rolling-stock and repairing-shops, was 4,000,000*l*. Owing to financial difficulties the works were abandoned, but the 64 miles constructed by Mr. Fowler, and the recent extensions of the same by the military, proved of great service to the expedition, even some of the steam launches being taken by railway to save delays at the cataracts.

During the siege of Paris the German forces were dependent upon supplies drawn from their base, and the army requirements were fully met by one line of railway running twelve to fourteen trains per day. Military authorities state that a train load of about 250 tons is equal to two days' rations and corn for an army corps of 37,000 men and 10,000 horses. The military operations in Egypt have proved that, even in the heart of Africa, railways, steamboats, electric lights, machine guns, and other offspring of mechanical science, are essential ingredients of success.

Members of this Section, who visited the United States last year not for the first time, could hardly have failed to notice that American and European engineering practice are gradually presenting fewer points of difference. Early American iron railway bridges were little more than the ordinary type of timber bridge done into iron, and the characteristic features, therefore, were great depth of truss, forged links, pins, screw-bolts, round or rectangular struts, cast-iron junction pieces, and, in brief, an assemblage of a number of independent members more or less securely bolted together, and not, as in European bridges, a solidly riveted mass of plates and angle-bars. At the present moment the typical American bridge is distinctly derived from the grafting of German practice on the original parent stock. Pin connections are still generally used in bridges of any size, but the top members and connections are more European than American in construction, whilst for girders of moderate span, such as those on the many miles of elevated railway in New York, riveted girders of purely European type are admittedly the cheapest and most durable. From my conversations with leading American bridge builders, I am satisfied that their future practice and our own will approach still more nearly. We should never think of building another Victoria tubular bridge across the St. Lawrence, or repeat the design of the fallen Tay bridge, nor would they again imitate in iron an old timber bridge, or repeat the design of the fallen Ashtabula bridge. In one respect the practice in America tends to the production of better and cheaper bridges than does our own practice, and it is this: each of the great

bridge-building firms adopts by preference a particular type design, and the works are laid out to produce bridges of this kind. It is an old adage that practice makes perfect, and by adhering to one type, and not vaguely wandering over the whole field of design, details are perfected and a really good bridge is the result. Engineers in America therefore need only specify the span of their bridge, and the rolling load to be provided for, with certain limiting stresses, and they can make sure of obtaining a number of tenders from different makers of bridges, varying somewhat in design, but complying with all the requirements. With us, on the other hand, it is too often the privilege of a pupil to try his 'prentice hand on the design for a bridge, and it is no wonder, therefore, that many curious bits of detail meet the eye of an observant foreigner inspecting our railways.

The magnificent steel wire rope suspension bridge of 1,600 feet span built by Roebling across the East River at New York well marks the advanced state of mechanical science in America as regards bridge building. It is worthy of note that, at the second meeting of the British Association, held so long back as 1832, there was a paper on suspension bridges, and the author entreated the attention of the scientific world, and particularly of civil engineers, to the serious consideration of the question: How far ought iron to be hereafter used for suspension bridges, since a steel bridge of equal strength and superior durability could be built at much less cost? 'I earnestly call upon the ironmasters of the United Kingdom,' said he, 'to lose no time in endeavouring to solve this question.' In this, as in many other engineering matters, Americans have given us a lead. America is, indeed, the paradise of mechanics. When the British Association was inaugurated, years ago, there was, I believe, no intention to have a section for the discussion of mechanical science. Possibly it may have been considered too mean a branch. Even the usually generous Shakespeare speaks contemptuously of 'mechanic slaves, with greasy aprons, rules, and hammers;' and our old friend Dr. Johnson's definition of 'mechanical' is 'mean, servile.' We have lived down this feeling of contempt, and the world admits that the 'greasy apron' is as honourable a badge as the priest's cassock or the warrior's coat of mail, and has played as important a part in the great work of civilising humanity and turning bloodthirsty savages into law-abiding citizens.

As I have had occasion to refer to Canada and America in the course of my remarks, I cannot refrain from expressing the high appreciation which I am sure every member of this Section entertains of the cordiality and warmth of our reception on the other side of the Atlantic last year. Such incidents make us forget that differences have ever existed between the two countries. I was amused the other day, on reading in Dr. Doran's 'Annals of the Stage' that, in the year 1777, the theatrical company from Edinburgh was captured on its voyage to Aberdeen by an American privateer, and taken off heaven knows where, for it did not turn up again. This, you will say, was a long time ago; but, if you glance through the speeches of our present gracious Sovereign, you will find one in which her Majesty speaks with 'deep concern' of insurrection in Lower Canada, and of hostile incursions into Upper Canada by certain 'lawless inhabitants' of the United States of North America.

This is strange reading, after our last year's experience. Gentlemen, I may not have carried you with me in some things I have said, but I think you will all agree with me in this: that the statesmen who should suffer any slight difference of opinion to develop into a serious breach between ourselves and our brethren in Canada and cousins in America would, to quote the words of Burke, 'far from being qualified to be directors of the great movements of this empire, be not fit even to turn a wheel in the machine.'

The following Papers were read:—

1. *The New Tay Viaduct. By* CRAWFORD BARLOW, *B.A., M.Inst.C.E.*
See Reports, p. 883.

2. *The Forth Bridge Works.* *By* ANDREW S. BIGGART, *C.E.*

See Reports, p. 873.

FRIDAY, SEPTEMBER 11.

The following Papers were read:—

1. *The American System of Oil Pipe Lines.* *By* J. H. HARRIS.

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2. *The Movement of Land in Aberdeen Bay.* *By* W. SMITH.

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3. *On Shallow-draught Screw-steamers for the Nile Expedition.* *By* J. T. THORNYCROFT, *M.Inst.C.E.*

A special feature of these steamers for use in shallow waters is the form of the hull in the neighbourhood of the propellers, it being such as to maintain a volume of water, like a wave, over the propellers, even though they should extend above the water-line of the vessel. The author demonstrated the serviceableness of such a form as early as 1875.

The second special feature is the kind of propeller used. It resembles a screw, but is placed in a tube having guides to direct the stream aft, and a conical body to contract the area of stream.

The principal dimensions of the Nile boats are given below:

	ft.	in.
Length of hull at water-line	140	0
Beam moulded	21	0
Load draught	2	3
Displacement	93·6 tons	

With a light draught of 2 feet aft, $67\frac{1}{2}$ tons displacement, a speed of 15·1 knots was obtained, while at the load draught trial, 2 feet 3 inches, the displacement being 93·6 tons, a speed of 14·17 knots was obtainable with an I H.-P. of 390. The displacement coefficient was 150.

The vessel is arranged to carry guns on its upper deck, which is supported on bullet-proof houses. On the fore part of the upper deck is a bullet-proof conning tower containing a steam steering engine.

The hull is of steel divided into water-tight compartments; the engines are of the same model as used in the torpedo-boats by the author's firm, and the boats are fitted with triple rudders in order to increase the steering power for the special purposes for which they are intended.

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4. *The Sphere and Roller Friction Gear.* *By* Professor H. S. HELE SHAW.

The author described before Section A last year the principles involved in the action of the 'sphere and roller' mechanism, a complete investigation of which is being published in the Philosophical Transactions of the Royal Society. Since that time the above principles have been further applied, the results of which may be seen in the mathematical instrument section and in the transmission of power section of the Inventions Exhibition. The object of the author in the present paper is to speak only of the latter application, giving the results of actual trial and a description of a new arrangement which is being made on a still larger scale.

The author, first by means of diagrams, briefly explained the principles of the mechanism, in which a change of the imaginary axis of revolution of the sphere is

effected by merely altering the position of one frame containing a set of wheels or rollers in contact with the sphere. The result of this change is that the relative velocity of two given rollers in a second or fixed frame are correspondingly altered. One of these latter wheels or rollers being employed as a driver, motion can be imparted to the sphere by frictional contact with it, and thus the second wheel or roller in the same frame can be employed as a follower and driven at any required velocity relatively to the first. After unsatisfactory experiments with a heavy ball, whereby force closure was substituted for pair closure, it was determined to return to the pair-closed arrangement, in which the necessary frictional contact was obtained by the pressure of suitably placed rollers, and the author's brother, Mr. Edward Shaw, designed and executed a machine which it was calculated would, at not excessive velocities, transmit nearly 2 H.-P. This was given the form of a sack hoist, which has been for some time in operation at the Exhibition. The author then described the details of this machine by means of diagrams. The action is in most respects highly satisfactory, there being almost perfectly silent action and an absence of all noise and vibration. By means of one small handle, which simply causes the movable frame to roll round on the sphere, and therefore is turned with scarcely any appreciable effort, not only is the hoisting of a small sack performed at any required speed, but the same handle when moved so as to cause the axis of rotation to pass between the driver and follower, instead of on one side of them, causes a reversal of motion and consequent lowering of the sack at any required speed. In the intermediate position, i.e. when the axis of rotation of the sphere passes through the point of contact of the follower, no motion ensues. Thus all necessity either for a starting and stopping gear or for a brake is avoided, and the whole operation is instantly performed by means of one handle.

Several difficulties had to be overcome, these being:

1. The question of finding suitable material.
2. Heating of bearings with the high speeds and pressures employed.
3. Variable resistance which occurs in different positions of the axis of rotation from want of true point contact.
4. Twisting of the sphere on point of contact with the following roller when the action of rotation passes through that point, and consequent injury of the surfaces in contact when the follower stops.

Difficulties 1 and 2 were completely overcome, the first by using hard elastic surfaces and phosphor bronze, being successfully tried in contact, and also good cast-iron on cast-iron; the second by using Stauffer's lubricators. The third difficulty has been partially and the fourth entirely overcome.

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5. *On the Employment of the Road Engine in Construction and Maintenance of Roads.*[1] *By* Colonel Innes.

The author first dealt with the historical aspect of road-making, then with the methods which the Kincardine o' Neil District of Aberdeenshire Road Trustees had in previous times adopted in maintaining the roads in that part of the country. They had been faced with so many difficulties that they were now applying steam power in the shape of an ordinary road engine. It had been in operation now for more than a year, and promised to be satisfactory. The method was—The employment of an engine in working a stone breaker, which provides large quantities of metal; the employment of the engine to draw waggons used in applying the metal; and the adaptation of the engine and waggons to act as rollers at the same time as they are employed in applying the metal, thus applying the metal, rolling it into solidity, and leaving a thoroughly finished surface. They had to deal with insufficiently constructed roads, and roads having the appearance of being well constructed, but when subjected to heavy locomotive engine traffic where the subsoil was soft they gave way. The engine and waggons in applying the metal found out all the weak places, and the yielding surface was coated with metal until it has

[1] Printed *in extenso* in the *Contract Journal*, September 28, 1885.

uniform strength with the rest of the roads. He proceeded to describe the engine, the stone breaker, and the working plant. The wheels of the waggons broke gauge, and by an adjustment of the coupling the eight wheels were made to cover a surface of eight feet wide, or, allowing for overlapping, would effectually roll a surface of from six to seven feet. The total cost of the plant was 1,104*l.* and this was inclusive of 309*l.* for the stone breaker and the van, so that the cost of the plant specially required was limited to the engine and waggons, or a cost of 795*l.* For a durable surface of road hand-broken metal was better, but the cost was considerably greater, being 2*s.* 8*d.* per cubic yard: while engine-broken metal cost 1*s.* 10*d.*, and this included cost of quarrying. He concluded by saying that it was seldom that so entirely novel system could be set inoperation without some partial failures or disappointments, but this had been an exception. It worked even better than was anticipated, the means were seen clearly whereby some details, which they left over to await experience, could be perfected, and they looked forward with confidence by means of this system to reconstructing and maintaining all the main lines of roads in the district, and to the increasing traffic which they had to carry without any additional cost to the ratepayers. And this too in a district where the condition of the roads was most unsatisfactory, and the prospect of improving them hopeless without an expenditure, which it was difficult to contemplate providing for.

SATURDAY, SEPTEMBER 12.

The Section did not meet.

MONDAY, SEPTEMBER 14.

The following Papers were read:—

1. *Electric Lighting and the Law. By* Dr. LEWIS EDMUNDS.

The author adduced evidence to show that the stagnation in the electric lighting industry arises, not from the fact that electric lighting cannot prove remunerative as a commercial undertaking if left to its own free development, as most other industries have been, but because electric lighting under the conditions imposed by Act of Parliament is commercially impossible. The public supply of electricity is now regulated by the Electric Lighting Act of 1882, and so long as that Act remains unamended or unrepealed, there is no opportunity for great development in electric lighting as a matter of public supply.

Directly the unfortunate companies sought an Act to give them the necessary powers there was a great outcry about monopoly, and the success of the present gas and water companies was held up to the public as the result of an *unfair* monopoly. Many people seemed to forget that the existing companies are the successful survivors of a large number, a considerable proportion of which have proved great losses. If there had not been some inducement to the original investors in the way of future profit we should probably have had many large towns still without a proper supply of gas and water. The Legislature seemed to forget how much we owe to the encouragement of private enterprise in this country, and that we are indebted to it for a better supply of gas and water than any other country in the world.

The electric lighting companies would not have any ground for complaint if the conditions imposed upon them by the Act had been a reasonable *quid pro quo* for the privilege of taking up roads or footpaths for their own purposes and the monopoly (more or less) of supplying a district. The fault of the Act is in placing such stringent conditions on persons supplying electricity, and in asking so much of them as to deprive them of opportunity to realise an adequate return for their outlay. The public grant certain concessions to a company, and it is just and

equitable that conditions should be imposed for the proper performance of the business in respect of which the privileges are obtained. If the public ask too much no one will take the other side of the bargain, and the Legislature extinguishes what it meant to regulate.

The section of the Act which has done nearly all the harm is section 27, which relates to compulsory purchases by the local authority of undertakings within the Act.

Shortly the section amounts to this. The local authority can, after 21 years, or at their option, after the expiration of any subsequent period of seven years, purchase compulsorily the undertaking within their jurisdiction, at the fair market value of the lands, buildings, works, materials, and plant merely as such without any addition, in respect of compulsory purchase or goodwill, or any profits made in the past, or to be made in the future.

If therefore the enterprise is unsuccessful it will be left on the investor's hands.

If successful, it will be compulsorily bought by the Local Authority for the mere value of the plant then in actual use, just when it has become a valuable property and he is beginning to reap the full advantage of his investment, which may be at the end of 21 years or of any subsequent seven year period.

By not giving the promoters any real interest in the undertaking, it would prevent any large expenditure on works, with a view to a permanent and lasting installation; their only object would be to make the maximum profit from the business while it lasted without any regard to the future.

The position stands somewhat thus:—

Parliament does not want to give anyone but the local authority a monopoly for more than 21 years.

It will not pay investors unless they get a monopoly for a much longer period.

The local authorities are not fit persons to undertake these speculative enterprises, even if they were justified in using the ratepayers' money for doubtful results.

The consequence is that, in its anxiety to prevent a monopoly, the Legislature has entirely deprived the general public of the comfort and security and other advantages which the electric light offers over all other forms of illumination.

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2. *On an Electric Safety Lamp for Miners.* *By* J. Wilson Swan, *M.A.*

No mere portable electric lamp being dependent upon extraneous wire connection, of which some exist under the name of 'Miners' lamps,' can be truly called a safety-lamp.

A hand-lamp, detached and portable, more or less like the ordinary safety-lamp, is an absolute necessity in order to comply with the conditions implied in the term 'Electric Safety-lamp.'

The subject of the present paper fulfils those conditions. It consists of two parts; the lamp proper, and the battery to feed it. The combined apparatus weighs only $6\frac{3}{4}$ lbs.; and the cylindrical case containing the cells measures 8 by 4 inches.

The battery consists of seven cells, and is thus constructed:—The core is a lead wire surrounded by peroxide of lead. This is covered by a wrapping of cloth, outside which, and filling the space between the oxide cylinder and the interior lead lining of the containing tube, is a packing of lead filament. The lead filament is in contact with the lead lining, and that with a strip of lead which forms one of the outward conductors; the lead wire forming the core of the oxide cylinder being the other conductor. The electrolyte is dilute sulphuric acid; adhesion to the lead filament prevents the liquid from spilling, if the battery is inclined.

The terminals are attached to two elastic strips of brass, and these hold the lamp between them with a slight end pressure, in a simple manner, so as to be easily removable.

The lamp, of a half-candle power, probably requires less current than any lamp hitherto made, viz. ·14 of an ampère; the electro-motive force being 12 to 13 volts. The cells can store sufficient energy to sustain the lamp during ten to twelve hours.

Contact is made and broken within a small cavity in the switch plate containing a single drop of oil. Even without this precaution, there is not the slightest danger of ignition of explosive gas by a spark produced at the switch on opening the circuit.

To charge, say five hundred lamps would neither be complicated nor costly; a dynamo absorbing three to four H.P. would suffice. The cells would be ranged on benches in front of fixed wires from the dynamo; and these would be so fitted with coupling plugs, that the connecting of several hundred batteries would be the work of a very short time.

The cost of the renewal of the electric would probably be about the same as the cost of filling, cleaning, and keeping in repair Davy lamps; or about *2d.* per lamp per week. The supply of oil for ordinary safety lamps costs another *2d.* per week; which would fully cover the cost of charging the batteries for the electric light.

Here, then, is a miner's lamp, to which the appellation of '*Safety*' may be given without any reservation; and one which is free from even the suspicion of causing an explosion of fire-damp. Besides its safety, there is one other advantage of occasional importance. Oil lamps require air more or less pure to support the combustion of the oil. There are, unfortunately, times, after an explosion of fire-damp, when the air of the pit is so foul that no oil lamp will burn in it. With this electric lamp, which requires no air, and with a Fleuss apparatus for breathing, the work of exploration might be carried on, and this, it is reasonable to hope, would be attended with the saving of life.

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3. *On the Strength of Telegraph Poles. By* W. H. PREECE, *F.R.S., M.Inst.C.E.*—See Reports, p. 853.

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4. *On Domestic Electric Lighting. By* W. H. PREECE, *F.R.S., M.Inst.C.E.*

After referring to the full details of the lighting installation of his house in Wimbledon, given to the section, at the meeting at Montreal, Mr. Preece referred generally to the experiences he had gained during the past twelve months. The secondary batteries, upon which he had mainly relied, exceeded his expectations in the services they rendered. They returned 70 per cent. of the energy put into them, without any apparent diminution whatever in their E. M. F. They showed no signs of deterioration and gave no trouble whatever. He used his gas engine for charging only two days a week. He had experienced no fault with the wiring of his house. He had used only the very best materials, and had attended personally to the insulation of the system. It was periodically tested and found to be good. He referred in severe terms to the cheap and nasty wire, which was so frequently and ignorantly used, and feared that the prejudice against the electric light would increase when failures from this cause arose. None but the very best materials should be used, and the joints should be seen to by experts.

He had devoted considerable attention to the problem of distributing light, and had succeeded so far that, while his rooms were beautifully illuminated, the eye was not irritated by regarding a bright source of light. The lamp he used was a 50-volt 10-candle power glow lamp, and it was, as a rule, so fixed that the eye never saw it. He had arrived at the use of these lamps after careful consideration and many trials of other lamps. They secured greater safety in the leads, and involved less capital in batteries through the use of low E. M. F.

He ran his lamp at an E. M. F. about two per cent less than the nominal E. M. F. He did this to secure long life to his lamps. The breakage had been very small. The E. M. F. and current which will give a lamp a normal life of 1,000 hours and a certain candle power, should be determined by every maker. The sixth power of the current will give the candle power, and the twenty-fifth power the life with any other current. The great advantage of batteries is, that the proper current once determined, can never be exceeded, and thus efficiency is ensured. If lamps are run too low, there is waste of power; if too high, there is waste of lamps. We are now gradually acquiring a thorough knowledge of the

number of volts which should be expended in each lamp to secure the maximum economic efficiency.

He had introduced into the charging lead and into the discharging lead a Ferranti meter, so that he was able to record exactly the quantity of electricity passed through the batteries, and that passed through the lamps. This beautiful meter is based on Ampère's laws, which determine the attraction and repulsion of currents. A small phosphor-bronze vane is immersed in a bath of mercury, through which the current flows radially, fixed in a magnetic field. The mercury rotates and carries with it the vane. The rate of rotation varies directly with the strength of current, and the number of rotations is recorded by a counter, which can be read off directly. So far, he was perfectly satisfied with its performance.

As regards expense, excepting the first cost, he did not find much addition to his expenditure for illumination. His electric light was costing him about 50*l.* a year for gas, wages, oil, and lamps. It was the cheapest luxury he indulged in. Its great advantages were the comfort and cheerfulness it engendered; and as cheerfulness was the main element of health, he thought that the electric light would prove a serious rival to the doctor. There was no one who valued health and comfort who should neglect to apply the electric light to his home when it was brought, as it has been by the success of the secondary battery, within his means. It was said that he, as an expert, could make things go which would fail in ordinary hands; but he instanced several cases where coachmen, butlers, gardeners, and grooms had been found perfectly competent and intelligent enough to attend to everything.

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5. *On a System of Periodic Clock Control on Telephone or Telegraph Lines.* *By* Professor W. F. Barrett, *F.R.S.E.*

The expense of maintaining separate lines for the sole purpose of synchronising the clocks in a town led the author to devise an arrangement some four years ago whereby telephone and telegraph lines could be utilised for clock control and also for burglar and fire alarm. Every subscriber to a telephone exchange is, by this means, enabled to have a main clock in his house kept in true time with the standard clock at the Telephone Exchange. This main clock at certain times switches off the telephone receiver and puts into circuit the electro-magnetic arrangement whereby the clock is synchronised. The method adopted for this purpose is a modification of Ritchie's system of hourly control, with a semaphore attached to indicate the true time to a fraction of a second. This main controlled clock, by a simple contact arrangement fitted to a disc on the arbor of the minute wheel, distributes time true to a minute throughout the establishment. This is accomplished by an electro-magnetic minute clock of novel and very simple construction, which however requires a diagram to describe. The main clock also switches off the telephone circuit during the night, and puts in its place the fire alarum circuit of the house, and also the circuit passing through a safe or air tight case, which circuit is instantly closed whenever a burglar attempts to force the safe. In this way the central exchange is automatically 'rung up,' and the correct house indicated whenever a fire breaks out or a burglar breaks in. The author stated he had had this system at work very satisfactorily for some time in his own laboratory.

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6. *Electric Lighting at the Forth Bridge Works.* *By* James N. Shoolbred, *B.A.*, *M.Inst.C.E.*—See Reports, p. 879.

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7. *On the Development of the Pneumatic System as applied to Telegraph purposes.* *By* J. W. Willmot.

It is probably not generally known by what means telegraphic messages are collected from the branch offices in large towns, and conveyed to the central office for transmission by wire. This service is performed by means of pneumatic tubes,

through which 'carriers' containing the actual written messages are propelled. The system was first introduced by Mr. L. Clark in 1854, who employed vacuum, drawing the carriers in one direction only. The first tube which came into operation was laid for the Electric Telegraph Company between their office in Lothbury and their branch office at the Stock Exchange. This tube was in continuous use for over twenty years and was in good condition when raised.

About the year 1866 Mr. C. F. Varley applied compressed air for propelling the carriers in the opposite direction from that in which they were drawn by vacuum, and very ingenious valves were designed by him for effecting the change from vacuum to pressure.

With each of the foregoing systems it was necessary after the transmission of a carrier to restore the pressure in the tube to the normal atmospheric pressure before another carrier could be despatched. This caused considerable delay and loss of engine-power.

In 1870 the author designed the double sluice valve which is now in general use, and by means of which carriers can be despatched continuously without stopping the flow of air in the tube.

The employment of pneumatic tubes in London has been continually increasing until the system, which in 1854 was represented by one 6 H.P. engine working a single tube a few yards in length, at the present time comprises four 50 H.P. engines (each indicating 130 H.P.) and forty-nine tubes, the aggregate length of which exceeds twenty-seven miles. These figures are exclusive of over a mile in short lengths of house tubes also worked by the engines, as well as of over a dozen hand-worked tubes in various metropolitan offices. The use of pneumatic tubes, however, has not been restricted to London alone, for in the provincial cities and towns there are sixty-three tubes which, with the London tubes, bring the total length of engine-worked tubes to upwards of thirty-nine miles. To these should be added ninety-five shorter hand-worked tubes. With the air-pressure employed an approximate speed of one mile in seventy seconds is attained in tubes not exceeding a mile in length. The speed varies inversely as the square of the length of the tube. The pipes generally employed are of lead, having an internal diameter of $2\frac{1}{4}$ inches.

At Liverpool a very complete pneumatic system has lately been installed. The number of tubes has been increased from eight to fourteen and three 30 H.P. beam engines (each indicating up to 90 H.P.) have been erected. These engines were designed and constructed under the personal supervision of the author, and were made by Messrs. Easton and Anderson of Whitehall Place, London, and Erith, Kent. The pumps are so arranged that either set can either exhaust or compress air. Two engines are sufficient for the present requirements, the third being spare in case of breakdown.

TUESDAY, SEPTEMBER 15.

The following Report and Papers were read :—

1. *Report of the Patent Law Committee.*—See Reports, p. 695.

2. *Autographic Apparatus for Machines for Testing Materials. By* Professor W. C. Unwin, *M.Inst.C.E.*

With the increasing use of steel in construction, the necessity of regular and systematic testing of the elastic properties of materials has become much more urgent. Rough bending and temper tests furnish, it is true, useful information as to the quality of steel. But no procedure furnishes information so reliable and accurate as a breaking test, carried out by means of a suitable machine; nor can the quality of the material be specified in any other way so definitely, as by requiring

that its breaking stress and its elongation or contraction should lie between assigned limits.

In the ordinary testing of materials, we observe the loads successively imposed and the corresponding deformation of the bar. If such a series of observations is plotted with the loads for ordinates and the elongations for abscissæ, and the points so found are connected by a curve, we get a stress and strain diagram showing at a glance the whole of the observations and indicating by its form the character of the material.

Now it is easy to see that such a diagram, like the indicator diagram of a steam engine, may be drawn autographically by the machine itself, and that the autographic diagram will have some advantages over the diagram plotted from discontinuous observations. It will be a continuous record at all stages of the test, it will be free from accidental errors of recording, and at all events it will save a great deal of trouble in making numerous successive observations.

The first autographic apparatus for testing machines was probably that attached by Thurston to his Torsion apparatus. But a Torsion machine is not usually employed in engineering tests. Not long after Polmeyer constructed a testing machine for tension tests with an autographic arrangement attached. This the author saw at Dortmund in 1883. Since then, Fairbanks in America, and Wicksteed in this country, have constructed autographic apparatus for ordinary testing machines.

The author designed an apparatus for recording tension tests in January 1883. That apparatus gave a diagram two feet square. Since then he has constructed a smaller and handier apparatus which is placed on the table.

In the author's testing machine the loading of the specimen is effected by a single weight of a ton travelling along a lever or steelyard about 20 feet long. The motion of the screw which drives the travelling weight is transferred exactly to a brass cylinder like the paper cylinder of a steam-engine indicator. The amount of the rotation of this is, therefore, exactly proportional to the load on the specimen. The pencil slides at the same time axially with a motion proportional to the extension of the specimen. This motion is obtained from a very thin wire, attached to the specimen, and strained over pullies, so that the motion of the pencil is double the actual extension. The wire is kept strained to a given tension by a weight of two or three ounces. By suitable choice of position of the autographic apparatus on the testing machine, the small vertical movement of the specimen in testing has no sensible influence on the record. It appears from check measurements that the record of the load is exact, and that of the extension has an error of at most $\frac{1}{100}$th of an inch.

The accuracy of the record of extension depends mainly on two arrangements. (1) The selection of a position for the recording apparatus such that no horizontal movement other than that to be recorded is communicated to the wire. (2) On the use of an extremely fine wire, which can be strained to straightness and kept free from bends by a very small weight. The form of the clips which define the length on which the extension is measured is also of importance. In the clips shown the specimen is held between a plane, a knife edge and a point, so that the clips are rigid as regards any tilting on the specimen, and at the same time precisely define the length on which the measurement is made.

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3. *Notes on Mild Steel.* *By* G. J. GORDON.

The first note was with reference to the corrosion of steel, which was shown to have now been proved by experience to be about the same as for wrought iron.

2nd. It was pointed out that shearing thick plates had the remarkable effect of rendering them cold short, and that this was completely cured by either annealing the plates or by planing off the rough edges left by the shears.

3rd. It was pointed out that the tendency of users of steel was towards employing that of higher tensile strains, and that there was no reason why this should not be done provided the same ductility and toughness are insisted on, as in the case of the milder steel now in use.

4th. The question of the use of thick plates for boilers was discussed, and the results of a series of experiments were given, which go to show that if the material is carefully made and tested, heated in proper furnaces, and bent without putting any undue strains upon them in the boiler maker's shop, it was just as safe to use plates for boilers from 1″ to $1\frac{1}{2}$″ thick, and weighing from 1 ton 10 cwt. to 2 tons 10 cwt., as it is to use those from $\frac{3}{8}$″ to 1′ thick and weighing from 10 cwt. to 1 ton 10 cwt.

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4. *The Diminution of Casualties at Sea.* *By* Don Artùro de Marcoartu.

The author in his paper made the following proposals:—1. That vessels be supplied with apparatus to communicate with and to telegraph to each other and to the nearest coast the weather and sea encountered by them; 2. That the steamers give more detailed reports about the weather and sea as soon as they arrive on both coasts, but more especially on the American coast, to the Navy Department and to the U.S. Signal Service; 3. That a special, regular, and permanent service be established on the American coast, supplied with the requisite means to receive all reports, and to transmit to Europe several warnings each day about the reports collected and the predictions bearing on the navigation; 4. That from the European coasts be communicated daily to the American coasts the state of the weather and sea for comparison with the predictions and for the continuous study of the sea and weather.

For advancing meteorological knowledge, and in the interest of navigation, he recommended the establishment of two more cables—one to connect Iceland and the Faroes with Europe, the other to connect Azores and Bermuda with Europe and America; as all the submarine cables connecting North America and North Europe have not intermediate stations on the middle Atlantic, and the great extent of the ocean renders reporting impossible.

In the charts of relative storm frequency in the Northern Hemisphere, prepared by the American Signal Service, and published only a few months ago, it is shown in the annual average of the relative storm frequency during twenty-one years, from 1864 to 1884, that the sea is most calm between the meridian 40° and 9° (near to the Iberian Peninsula), and from latitude 40° at the first meridian to latitude 46° at long. 1°; and stormy towards the latitudes of Newfoundland, and ascending from their parallels to the north of Ireland.

The last limit of the most frequent icebergs, according to the observations collected by the Hydrographer of the United States Navy Department, was near 40° latitude; and therefore the track from the United States to Lisbon is to the south of the icebergs.

Professor Graham Bell published a few months ago the results of some experiments to detect by echo the proximity of vessels and wrecks. The experiments were made on the River Patapsco, about seven miles from Baltimore. The apparatus employed consisted of a musket, to the muzzle of which a speaking-trumpet was attached. From this musket blank cartridges were fired when passing vessels, and after a longer or shorter time, according to the distance of the vessels, an echo was returned.

The author called attention years ago to the great power of ice for reflecting sound, and believes the possibility of obtaining an echo from an iceberg, when in dangerous proximity to a ship, is worth a trial at sea. Both apparatus, the thermopiles combined with the trumpet, and the steam-whistle and siren, ought to be used; but it is better to select a route away from bergs, fields, and fogs, which have caused the loss of so many vessels. Parry says, in the account of his Polar Expedition, that two men conversed distinctly at a distance of a mile and a quarter.

Fires.

To lessen the risk from fire 'automatic sprinklers for fire extinction' and 'fire alarms' are required in some parts of the ship, especially in connection with inflammatory goods.

The principle of 'fire alarms' and 'automatic sprinklers' is well known. In the fire alarms a sudden rise of temperature expands a spring, which moves a screw or another piece to complete an electrical circuit, and the bell or alarm is sounded. The principle of the automatic sprinkler is a pipe of water covered or sealed by a metal cap secured only by soldering some alloys melting at, say, 150 degrees Fahrenheit. When this temperature is reached, the cover is melted, and the water thrown with the volume required. These automatic sprinklers are coming into general use in the mills of the United States. As the cost of fixing the alarm and the sprinkler is small, the combination of both appliances is desirable.

Collisions.

To avoid collision with other vessels, the International Code prescribes the use of the steam-whistle at intervals of not more than two minutes.

In fog the only practical signal to-day is sound; but the existing signals must be improved and an international code of signals showing at once the direction of the approaching vessel introduced. Many telegraphic codes can be suggested for that purpose.

The speed of steamers in a fog must be fixed according to the strength of the alarm sounds and the power of controlling the movements of the vessel. If the alarm is heard at long distances and is sounded frequently, and the control of the vessel is easy, it is possible to proceed at greater speed than if the alarm were less well heard, not sounded so frequently, and the management of the ship difficult.

Automatically, and at the same time that the direction of the helm is changed to avoid the collision, the movement must be signalled very distinctly to the other vessels, and the exterior of the ships and the sea must be electrically illuminated. Several appliances can be employed for that purpose, to avert collisions, and to give full light, in the event of a disaster, for rescue.

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5. *On the Deep Sea Channel into Swansea Harbour.*[1] *By* Robert Capper.

Describes the cutting of the new deep sea channel into Swansea Harbour, without piers or other protective works, about one-fifth excavated four years ago with hired plant, commencing to dredge in from sea from the centre of Swansea Bay (which did not silt up), and the remainder in the immediate past twelve months, the whole 7,000 feet in length, 200 feet wide at top, 150 feet at bottom, and 14 feet in depth below the old bed of the bay, involving the digging, lifting, and carrying away two million tons of material to a distance of seven miles, gives some account of the geological formation met with, details of the cost, and how the time was spent whilst the work was in hand.

This channel opens Swansea to the largest class of shipping afloat any tide of the year; indeed, turning the neap tides into a blessing, and making the port available as a point of departure for any ship every night of the year at one given hour.

Points out that, at the beginning of the present century, there was scarcely any town of importance in the kingdom that was distant from navigation more than fifteen miles, most of the canals of that period having proved very profitable property. Yet the money spent in docks and harbours around our shores in the last one hundred years to receive the commerce of the whole world, is only double that invested in English canals; our seaports have not kept pace with our shipping, the 500 creeks and harbours, half managed by public bodies, have been allowed to silt up with very few exceptions, opening a wide field for the engineer, as it costs half as much to bring deep water to our doors as to go out to deep water with piers and quays.

Touches upon the deepening of the rivers St. Lawrence, Tyne, Clyde, and Scheldt as examples, the shipping trade of the latter having increased twentyfivefold in recent years.

[1] Published *in extenso* in *Engineering*.

Advocates a return to 'pool' harbours for those silted up, and observes that, although one hundred years ago London absorbed four-fifths of the English shipping trade, it now has only one-fourth; yet it is still the largest port in the world, Antwerp ranking second.

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6. *On the Spey Bridge at Garmouth and the River Spey. By* P. M. BARNETT.

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7. *On a New Form of High Speed Friction Driving Gear. By* Professor J. A. EWING.

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8. *On Ashton's New Power Meter. By* Professor H. S. HELE SHAW.

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9. *On the British Association Standard Gauge for Small Screws. By* EDWARD RIGG, *M.A.*

At the suggestion of the Mechanical Section a Committee was appointed by the British Association at Southampton in 1882, for the purpose of determining a gauge for the manufacture of the various small screws used in telegraphic and electrical apparatus, in clockwork, and for other analogous purposes. This Committee presented its final report at the Montreal meeting, and it will be of interest to the Section to know that progress has already been made towards the general adoption of the standard series of screws then recommended.

They have been officially adopted by the Telegraph Department of the Post Office, and this step alone may be relied upon to ensure their general adoption by the telegraphic and electric instrument trades in the course of a few years. The entire series of standard taps and dies has not yet been manufactured, but such as have been completed are now on view at the Inventions Exhibition, where they have been awarded a diploma of honour by the Jury Commission.

It will naturally be more difficult to secure their general introduction throughout the clock and watchmaking and other analogous industries, but important help may be expected in reference to these branches, from the fact that in Switzerland, where the system adopted by the British Association originated, an identical series of screws has already secured the support of the leading manufacturers, and the plates and finished screws will very shortly be placed on the market.

SECTION H.—ANTHROPOLOGY.

PRESIDENT OF THE SECTION—FRANCIS GALTON, M.A., F.R.S., President of the Anthropological Institute.

[For Mr. Galton's Address, see p. 1,206.]

THURSDAY, SEPTEMBER 10.

The following Papers were read:—

1. *The Scope of Anthropology, and its relation to the Science of Mind.*[1] *By* ALEXANDER BAIN, *LL.D.*

The author first reviewed the definition and scope of anthropology, as indicated by the leading authorities and by the usage of the British Association. He endeavoured to point out that the bringing together of the six departments—named, respectively, man's place in nature, the origin of man, the classification of races, the antiquity of man, language, and the development of civilisation—does not contribute to the mutual elucidation of the several topics, but merely concentrates into one whole the subjects connected with the higher mysteries of man's origin and destination.

The remainder of the paper was occupied with a survey of the researches conducted in the Section, having in view precise measurements of the bodily and mental characteristics of human beings. The author indicated various lines wherein these researches may be carried out so as to reflect new lights on our intellectual constitution. The examination for delicacy in the sense of colour is not the only important determination relating to vision. Equally, if not more important, is the testing of the sensibility to visual form and magnitude. So in hearing, both musical quality and articulate delicacy are susceptible of exact measurement. Likewise muscular discrimination is an ascertainable quantity, and of great importance in assigning the aptitude for manual skill.

The author also adverted to the research into the conditions and the measure of memory, as wholly within the means of accurate experimental determination; also the important intellectual function of seeing similarity in the midst of diversity, which can be reduced to more or less precision of estimate by suitable means. Taking along with these results the inquiries into the faculties of the lower animals, the author put especial stress upon the number and the delicacy of their senses, as the foundation of every attempt to explain the higher aptitudes. Intelligence commences with the power of discrimination, and increases as that power increases. The record of marvellous feats of exceptional ingenuity is of very little aid in revealing the secrets of the animal mind.

In conclusion, the author urged the admission of psychology, in a more avowed and systematic form, into the Anthropological Section. He would exclude the topics of metaphysical and ethical controversy, and welcome all the experimental researches into the intellectual and emotional regions of the mind.

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[1] Printed *in extenso* in the *Journal of the Anthropological Institute*, vol. xv. No. 3, February 1886.

2. *The Index of the Pelvic Brim as a Basis of Classification.*[1] *By* Professor W. Turner, *M.B.*, *F.R.S.*

That the inlet to the human pelvis presented variations in outline, and in the proportions of its conjugate and transverse diameters, has been recognised since the publication by Vrolik in 1826, and by M. J. Weber in 1830, of their important memoirs on the pelvis in certain races of men. In 1866, Zaaijer of Leyden, in his study of the pelvis in women of Java, recognised differences in form in women of that race. He expressed these differences numerically, taking the transverse diameter as = 100, and then multiplying the conjugate diameter by 100, and dividing by the transverse; the numeral so obtained is the index of the pelvic brim or pelvic index.

By applying this method to the pelvis in different races of men, a classification of races based on the index of the brim may be framed. In carrying out this method the male pelvis should especially be studied, as in women the pelvis, for sexual reasons, does not present such wide divergencies in the form of its inlet as in men. To give precision to the classification it will be advisable to employ special terms, and in order as far as possible to bring these terms into accordance with those employed in the classification of crania based on differences in the relations of the length to the breadth of the skull, Greek terms will be employed. Taking the Greek word πέλλα as equivalent to the Latin pelvis, *dolichopellic* will signify a pelvis the conjugate diameter of which is longer than the transverse or closely approaching to it; *platypellic*—a pelvis in which the transverse diameter greatly exceeds the conjugate; *mesatipellic*—a pelvis in which the transverse diameter is not so greatly in excess of the conjugate.

Owing to the comparatively limited number of pelves in the different races of men which have been measured, it may not be possible to fix definitely at present the numerical limits of each of these three groups, but the author assumes that a pelvis with a brim index above 95 is dolichopellic; one with a brim index below 90 is platypellic; one with a brim index between 90 and 95, both inclusive, is mesatipellic. In classing the races of men in one or other of these groups, both the author's own measurements on the pelves of various races and the published measurements of others have been taken. Whilst in some races the observations have been sufficiently numerous to enable one to speak definitely of the mean index of the race, in others, unfortunately, the observations are too few to permit one to do more than give a provisional classification.

The detailed measurements on which this classification is based will be found in the 'Report on the Bones of the Skeleton collected during the Voyage of H.M.S. "Challenger,"' now in the press.

Dolichopellic.	*Mesatipellic.*	*Platypellic.*
Australians.	Negros.	Europeans.
Bushmen.	Tasmanians.	Laplanders?
Hottentots.	New Caledonians.	Esquimaux?
Kaffirs.	Melanesians?	Guanche?
Andamans.	—	Chinese.
Aïno?	—	Mongolians generally?
Malays.	—	American Indians?
Newzealanders?	—	—

When a pelvis has dolichopellic characters it approximates in the relations of its transverse and conjugate diameters to the form of the pelvic brim met with in mammals lower than man. In the dolichopellic Australians, Bushmen, Kaffirs, and Andamanese the sacral length is, on the average, of greater diameter than the breadth, and this also is an animal character.

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[1] Published *in extenso* in the *Journal of Anatomy and Physiology*, October 1885.

3. *A Portable Scale of Proportions of the Human Body.* *By* W. F. STANLEY, *F.G.S., F.R.M.S.*

This instrument is a small thin scale or rule of ivory, of about three inches in length and three-quarters of an inch in width. It is divided on each edge of the two faces by lines which represent the proportions of the human body; the male on one side, and the female on the other. The lines are marked with the words, crown, eye, chin, shoulder, teat, navel, hand, &c. The scales of proportions which the lines represent are taken from measurements of the diagrams of the assumed perfect human forms given by John Marshall, F.R.S., F.R.C.S., in his work, 'A Rule of Proportion for the Human Figure.' The opposite edge to that on which the proportions are shown is divided into 100 parts in the same space as the height of the body, the tens being indicated by figures.

The object aimed at by the use of this proportional scale is to compare any person, or statue, or photograph, with the model of perfect form given by Marshall, or to divide the parts of the body in proportional decimals of the whole for description. The method of using the scale is to hold it up before the eye, facing the object at such a distance that the subtended angle from the two extreme lines on the scale may coincide with the crown and sole of the human form observed. When held in this position any intermediate part of the body may be easily compared for its position with that of of the perfect form by looking over the edge of the scale, or be measured off in decimal parts of the total height by looking over the other edge. A very little practice is sufficient to do this with considerable accuracy from life, or from a statue or a photograph. It is suggested that this scale may be very useful in giving approximately exact descriptions of the proportions of people of various races from observation, or of comparing individuals of races among themselves; also for artists and designers for giving the best proportions of the human figure.

The PRESIDENT delivered the following Address:—

THE object of the Anthropologist is plain. He seeks to learn what mankind really are in body and mind, how they came to be what they are, and whither their races are tending; but the methods by which this definite inquiry has to be pursued are extremely diverse. Those of the geologist, the antiquarian, the jurist, the historian, the philologist, the traveller, the artist, and the statistician are all employed, and the Science of Man progresses through the help of specialists. Under these circumstances, I think it best to follow an example occasionally set by presidents of sections, by giving a lecture rather than an address, selecting for my subject one that has long been my favourite pursuit, on which I have been working with fresh data during many recent months, and about which I have something new to say.

My data were the Family Records entrusted to me by persons living in all parts of the country, and I am now glad to think that the publication of some first-fruits of their analysis will show to many careful and intelligent correspondents that their painstaking has not been thrown away. I shall refer to only a part of the work already completed, which in due time will be published,[1] and must be satisfied if, when I have finished this address, some few ideas that lie at the root of heredity shall have been clearly apprehended, and their wide bearings more or less distinctly perceived. I am the more desirous of speaking on heredity, because, judging from private conversations and inquiries that are often put to me, the popular views of what may be expected from inheritance seem neither clear nor just.

The subject of my remarks will be Types and their Inheritance. I shall discuss the conditions of the stability and instability of types, and hope in doing so to place beyond doubt the existence of a simple and far-reaching law that governs hereditary transmission, and to which I once before ventured to draw attention, on far more slender evidence than I now possess.

[1] The data upon which the remarks in this Address are based, together with copies of the illustrated diagrams suspended at the meeting, are published in the *Journal of the Anthropological Institute*, November 1885.—F. G.

It is some years since I made an extensive series of experiments on the produce of seeds of different size but of the same species. They yielded results that seemed very noteworthy, and I used them as the basis of a lecture before the Royal Institution on February 9, 1877. It appeared from these experiments that the offspring did *not* tend to resemble their parent seeds in size, but to be always more mediocre than they—to be smaller than the parents, if the parents were large; to be larger than the parents, if the parents were very small. The point of convergence was considerably below the average size of the seeds contained in the large bagful I bought at a nursery-garden, out of which I selected those that were sown.

The experiments showed further that the mean filial regression towards mediocrity was directly proportional to the parental deviation from it. This curious result was based on so many plantings, conducted for me by friends living in various parts of the country, from Nairn in the north to Cornwall in the south, during one, two, or even three generations of the plants, that I could entertain no doubt of the truth of my conclusions. The exact ratio of regression remained a little doubtful, owing to variable influences; therefore I did not attempt to define it. After the lecture had been published, it occurred to me that the grounds of my misgivings might be urged as objections to the general conclusions. I did not think them of moment, but as the inquiry had been surrounded with many small difficulties and matters of detail, it would be scarcely possible to give a brief and yet a full and adequate answer to such objections. Also, I was then blind to what I now perceive to be the simple explanation of the phenomenon, so I thought it better to say no more upon the subject until I should obtain independent evidence. It was anthropological evidence that I desired, caring only for the seeds as means of throwing light on heredity in man. I tried in vain for a long and weary time to obtain it in sufficient abundance, and my failure was a cogent motive, together with others, in inducing me to make an offer of prizes for family records, which was largely responded to, and furnished me last year with what I wanted. I especially guarded myself against making any allusion to this particular inquiry in my prospectus, lest a bias should be given to the returns. I now can securely contemplate the possibility of the records of height having been frequently drawn up in a careless fashion, because no amount of unbiassed inaccuracy can account for the results, contrasted in their values but concurrent in their significance, that are derived from comparisons between different groups of the returns.

An analysis of the records fully confirms and goes far beyond the conclusions I obtained from the seeds. It gives the numerical value of the regression towards mediocrity as from 1 to $\frac{2}{3}$ with unexpected coherence and precision, and it supplies me with the class of facts I wanted to investigate—the degrees of family likeness in different degrees of kinship, and the steps through which special family peculiarities become merged into the typical characteristics of the race at large.

The subject of the inquiry on which I am about to speak was Hereditary Stature. My data consisted of the heights of 930 adult children and of their respective parentages, 205 in number. In every case I transmuted the female statures to their corresponding male equivalents and used them in their transmuted form, so that no objection grounded on the sexual difference of stature need be raised when I speak of averages. The factor I used was 1·08, which is equivalent to adding a little less than one-twelfth to each female height. It differs a very little from the factors employed by other anthropologists, who, moreover, differ a trifle between themselves; anyhow it suits my data better than 1·07 or 1·09. The final result is not of a kind to be affected by these minute details, for it happened that, owing to a mistaken direction, the computer to whom I first entrusted the figures used a somewhat different factor, yet the result came out closely the same.

I shall explain with fulness why I chose stature for the subject of inquiry, because the peculiarities and points to be attended to in the investigation will manifest themselves best by doing so. Many of its advantages are obvious enough, such as the ease and frequency with which its measurement is made, its practical constancy during thirty-five years of middle life, its small dependence on differ-

ences of bringing up, and its inconsiderable influence on the rate of mortality. Other advantages which are not equally obvious are no less great. One of these lies in the fact that stature is not a simple element, but a sum of the accumulated lengths or thicknesses of more than a hundred bodily parts, each so distinct from the rest as to have earned a name by which it can be specified. The list of them includes about fifty separate bones, situated in the skull, the spine, the pelvis, the two legs, and the two ankles and feet. The bones in both the lower limbs are counted, because it is the average length of these two limbs that contributes to the general stature. The cartilages interposed between the bones, two at each joint, are rather more numerous than the bones themselves. The fleshy parts of the scalp of the head and of the soles of the feet conclude the list. Account should also be taken of the shape and set of many of the bones which conduce to a more or less arched instep, straight back, or high head. I noticed in the skeleton of O'Brien, the Irish giant, at the College of Surgeons, which is, I believe, the tallest skeleton in any museum, that his extraordinary stature of about 7 feet 7 inches would have been a trifle increased if the faces of his dorsal vertebræ had been more parallel and his back consequently straighter.

The beautiful regularity in the statures of a population, whenever they are statistically marshalled in the order of their heights, is due to the number of variable elements of which the stature is the sum. The best illustrations I have seen of this regularity were the curves of male and female statures that I obtained from the careful measurements made at my Anthropometric Laboratory in the International Health Exhibition last year. They were almost perfect.

The multiplicity of elements, some derived from one progenitor, some from another, must be the cause of a fact that has proved very convenient in the course of my inquiry. It is that the stature of the children depends closely on the average stature of the two parents, and may be considered in practice as having nothing to do with their individual heights. The fact was proved as follows:—After transmuting the female measurements in the way already explained, I sorted the children of parents who severally differed 1, 2, 3, 4, and 5 or more inches into separate groups. Each group was then divided into similar classes, showing the number of cases in which the children differed 1, 2, 3, &c. inches from the common average of the children in their respective families. I confined my inquiry to large families of six children and upwards, that the common average of each might be a trustworthy point of reference. The entries in each of the different groups were then seen to run in the same way, except that in the last of them the children showed a faint tendency to fall into two sets, one taking after the tall parent, the other after the short one. Therefore, when dealing with the transmission of stature from parents to children, the average height of the two parents, or, as I prefer to call it, the 'mid-parental' height, is all we need care to know about them.

It must be noted that I use the word parent without specifying the sex. The methods of statistics permit us to employ this abstract term, because the cases of a tall father being married to a short mother are balanced by those of a short father being married to a tall mother. I use the word parent to save a complication due to a fact brought out by these inquiries, that the height of the children of both sexes, but especially that of the daughters, takes after the height of the father more than it does after that of the mother. My present data are insufficient to determine the ratio satisfactorily.

Another great merit of stature as a subject for inquiries into heredity is that marriage selection takes little or no account of shortness or tallness. There are undoubtedly sexual preferences for moderate contrast in height, but the marriage choice appears to be guided by so many and more important considerations that questions of stature exert no perceptible influence upon it. This is by no means my only inquiry into this subject, but, as regards the present data, my test lay in dividing the 205 male parents and the 205 female parents each into three groups—tall, medium, and short (medium being taken as 67 inches and upwards to 70 inches), and in counting the number of marriages in each possible combination between them. The result was that men and women of contrasted heights, short

and tall or tall and short, married just about as frequently as men and women of similar heights, both tall or both short; there were 32 cases of the one to 27 of the other. In applying the law of probabilities to investigations into heredity of stature, we may regard the married folk as couples picked out of the general population at haphazard.

The advantages of stature as a subject in which the simple laws of heredity may be studied will now be understood. It is a nearly constant value that is frequently measured and recorded, and its discussion is little entangled with considerations of nurture, of the survival of the fittest, or of marriage selection. We have only to consider the mid-parentage and not to trouble ourselves about the parents separately. The statistical variations of stature are extremely regular, so much so that their general conformity with the results of calculations based on the abstract law of frequency of error is an accepted fact by anthropologists. I have made much use of the properties of that law in cross-testing my various conclusions, and always with success.

The only drawback to the use of stature is its small variability. One-half of the population with whom I dealt varied less than 1·7 inch from the average of all of them, and one-half of the offspring of similar mid-parentages varied less than 1·5 inch from the average of their own heights. On the other hand, the precision of my data is so small, partly due to the uncertainty in many cases whether the height was measured with the shoes on or off, that I find by means of an independent inquiry that each observation, taking one with another, is liable to an error that as often as not exceeds $\frac{2}{3}$ of an inch.

It must be clearly understood that my inquiry is primarily into the inheritance of different degrees of tallness and shortness. That is to say, of measurements made from the crown of the head to the level of mediocrity, upwards or downwards as the case may be, and not from the crown of the head to the ground. In the population with which I deal the level of mediocrity is $68\frac{1}{4}$ inches (without shoes). The same law applying with sufficient closeness both to tallness and shortness, we may include both under the single head of deviations, and I shall call any particular deviation a 'deviate.' By the use of this word and that of 'mid-parentage' we can define the law of regression very briefly. It is that the height-deviate of the offspring is, on the average, two-thirds of the height-deviate of its mid-parentage.

If this remarkable law had been based only on experiments on the diameters of the seeds, it might well be distrusted until confirmed by other inquiries. If it were corroborated merely by the observations on human stature, of which I am about to speak, some hesitation might be expected before its truth could be recognised in opposition to the current belief that the child tends to resemble its parents. But more can be urged than this. It is easily to be shown that we ought to expect filial regression, and that it should amount to some constant fractional part of the value of the mid-parental deviation. It is because this explanation confirms the previous observations made both on seeds and on men that I feel justified on the present occasion in drawing attention to this elementary law.

The explanation of it is as follows. The child inherits partly from his parents, partly from his ancestry. Speaking generally, the further his genealogy goes back, the more numerous and varied will his ancestry become, until they cease to differ from any equally numerous sample taken at haphazard from the race at large. Their mean stature will then be the same as that of the race; in other words, it will be mediocre. Or, to put the same fact into another form, the most probable value of the mid-ancestral deviates in any remote generation is zero.

For the moment let us confine our attention to the remote ancestry and to the mid-parentages, and ignore the intermediate generations. The combination of the zero of the ancestry with the deviate of the mid-parentage is that of nothing with something, and the result resembles that of pouring a uniform proportion of pure water into a vessel of wine. It dilutes the wine to a constant fraction of its original alcoholic strength, whatever that strength may have been.

The intermediate generations will each in their degree do the same. The mid-deviate of any one of them will have a value intermediate between that of the mid-

parentage and the zero value of the ancestry. Its combination with the mid-parental deviate will be as if, not pure water, but a mixture of wine and water in some definite proportion had been poured into the wine. The process throughout is one of proportionate dilutions, and therefore the joint effect of all of them is to weaken the original wine in a constant ratio.

We have no word to express the form of that ideal and composite progenitor, whom the offspring of similar mid-parentages most nearly resemble, and from whose stature their own respective heights diverge evenly, above and below. He, she, or it, may be styled the 'generant' of the group. I shall shortly explain what my notion of a generant is, but for the moment it is sufficient to show that the parents are not identical with the generant of their own offspring.

The average regression of the offspring to a constant fraction of their respective mid-parental deviations, which was first observed in the diameters of seeds, and then confirmed by observations on human stature, is now shown to be a perfectly reasonable law which might have been deductively foreseen. It is of so simple a character that I have made an arrangement with one movable pulley and two fixed ones by which the probable average height of the children of known parents can be mechanically reckoned. This law tells heavily against the full hereditary transmission of any rare and valuable gift, as only a few of many children would resemble their mid-parentage. The more exceptional the gift, the more exceptional will be the good fortune of a parent who has a son who equals, and still more if he has a son who overpasses him. The law is even-handed; it levies the same heavy succession-tax on the transmission of badness as well as of goodness. If it discourages the extravagant expectations of gifted parents that their children will inherit all their powers, it no less discountenances extravagant fears that they will inherit all their weaknesses and diseases.

The converse of this law is very far from being its numerical opposite. Because the most probable deviate of the son is only two-thirds that of his mid-parentage, it does not in the least follow that the most probable deviate of the mid-parentage is $\frac{3}{2}$, or $1\frac{1}{2}$ that of the son. The number of individuals in a population who differ little from mediocrity is so preponderant that it is more frequently the case that an exceptional man is the somewhat exceptional son of rather mediocre parents, than the average son of very exceptional parents. It appears from the very same table of observations by which the value of the filial regression was determined, when it is read in a different way, namely, in vertical columns instead of in horizontal lines, that the most probable mid-parentage of a man is one that deviates only one-third as much as the man does. There is a great difference between this value of $\frac{1}{3}$ and the numerical converse mentioned above of $\frac{3}{2}$; it is four and a half times smaller, since $4\frac{1}{2}$, or $\frac{9}{2}$, being multiplied into $\frac{1}{3}$, is equal to $\frac{3}{2}$.

Let it not be supposed for a moment that these figures invalidate the general doctrine that the children of a gifted pair are much more likely to be gifted than the children of a mediocre pair. What it asserts is that the ablest child of one gifted pair is not likely to be as gifted as the ablest of all the children of very many mediocre pairs. However, as, notwithstanding this explanation, some suspicion may remain of a paradox lurking in these strongly contrasted results, I will explain the form in which the table of data was drawn up, and give an anecdote connected with it. Its outline was constructed by ruling a sheet into squares, and writing a series of heights in inches, such as 60 and under 61, 61 and under 62, &c., along its top, and another similar series down its side. The former referred to the height of offspring, the latter to that of mid-parentages. Each square in the table was formed by the intersection of a vertical column with a horizontal one, and in each square was inserted the number of children out of the 930 who were of the height indicated by the heading of the vertical column, and who at the same time were born of mid-parentages of the height indicated at the side of the horizontal column. I take an entry out of the table as an example. In the square where the vertical column headed[1] 69– is intersected by the horizontal

[1] A matter of detail is here ignored which has nothing to do with the main principle, and would only serve to perplex if I described it.

column by whose side 67– is marked, the entry 38 is found; this means that out of the 930 children 38 were born of mid-parentages of 69 and under 70 inches who also were 67 and under 68 inches in height. I found it hard at first to catch the full significance of the entries in the table, which had curious relations that were very interesting to investigate. Lines drawn through entries of the same value formed a series of concentric and similar ellipses. Their common centre lay at the intersection of the vertical and horizontal lines, that corresponded to $68\frac{1}{4}$ inches. Their axes were similarly inclined. The points where each ellipse in succession was touched by a horizontal tangent, lay in a straight line inclined to the vertical in the ratio of $\frac{2}{3}$; those where they were touched by a vertical tangent, lay in a straight line inclined to the horizontal in the ratio of $\frac{1}{3}$. These ratios confirm the values of average regression already obtained by a different method, of $\frac{2}{3}$ from mid-parent to offspring and of $\frac{1}{3}$ from offspring to mid-parent. These and other relations were evidently a subject for mathematical analysis and verification. They were all clearly dependent on three elementary data, supposing the law of frequency of error to be applicable throughout; these data being (1) the measure of racial variability, (2) that of co-family variability (counting the offspring of like mid-parentages as members of the same co-family), and (3) the average ratio of regression. I noted these values, and phrased the problem in abstract terms such as a competent mathematician could deal with, disentangled from all reference to heredity, and in that shape submitted it to Mr. J. Hamilton Dickson, of St. Peter's College, Cambridge. I asked him kindly to investigate for me the surface of frequency of error that would result from these three data, and the various particulars of its sections, one of which would form the ellipses to which I have alluded.

I may be permitted to say that I never felt such a glow of loyalty and respect towards the sovereignty and magnificent sway of mathematical analysis as when his answer reached me, confirming, by purely mathematical reasoning, my various and laborious statistical conclusions with far more minuteness than I had dared to hope, for the original data ran somewhat roughly, and I had to smooth them with tender caution. His calculation corrected my observed value of mid-parental regression from $\frac{1}{3}$ to $\frac{6}{17{\cdot}6}$, the relation between the major and minor axis of the ellipses was changed 3 per cent., their inclination was changed less than 2°. It is obvious, then, that the law of error holds throughout the investigation with sufficient precision to be of real service, and that the various results of my statistics are not casual determinations, but strictly interdependent.

In the lecture at the Royal Institution to which I have referred, I pointed out the remarkable way in which one generation was succeeded by another that proved to be its statistical counterpart. I there had to discuss the various agencies of the survival of the fittest, of relative fertility, and so forth; but the selection of human stature as the subject of investigation now enables me to get rid of all these complications and to discuss this very curious question under its simplest form. How is it, I ask, that in each successive generation there proves to be the same number of men per thousand, who range between any limits of stature we please to specify, although the tall men are rarely descended from equally tall parents, or the short men from equally short? How is the balance from other sources so nicely made up? The answer is that the process comprises two opposite sets of actions, one concentrative and the other dispersive, and of such a character that they necessarily neutralise one another, and fall into a state of stable equilibrium. By the first set, a system of scattered elements is replaced by another system which is less scattered; by the second set, each of these new elements becomes a centre whence a third system of elements are dispersed. The details are as follows:—In the first of these two stages, the units of the population group themselves, as it were by chance, into married couples, whence the mid-parentages are derived, and then by a regression of the values of the mid-parentages the true generants are derived. In the second stage each generant is a centre whence the offspring diverge. The stability of the balance between the opposed tendencies is due to the regression being proportionate to the deviation; it acts like a spring against a weight.

A simple equation connects the three data of race variability, of the ratio of regression, and of co-family variability, whence, if any two are given, the third may be found. My observations give separate measures of all three, and their values fit well into the equation, which is of the simple form—

$$v^2\frac{p^2}{2}+f^2=p^2,$$

where $v=\frac{2}{3}, p=1{\cdot}7, f=1{\cdot}5$.

It will therefore be understood that a complete table of mid-parental and filial heights may be calculated from two simple numbers.

It will be gathered from what has been said, that a mid-parental deviate of one unit implies a mid-grandparental deviate of $\frac{1}{3}$, a mid-ancestral unit in the next generation of $\frac{1}{9}$, and so on. I reckon from these and other data, by methods that I cannot stop to explain, that the heritage derived on an average from the mid-parental deviate, independently of what it may imply or of what may be known concerning the previous ancestry, is only $\frac{1}{2}$. Consequently, that similarly derived from a single parent is only $\frac{1}{4}$, and that from a single grandparent is only $\frac{1}{16}$.

The most elementary data upon which a complete table of mid-parental and filial heights admits of being constructed, are (1) the ratio between the mid-parental and the rest of the ancestral influences, and (2) the measure of the co-family variability.

I cannot now pursue the numerous branches that spring from the data I have given, as from a root. I will not speak of the continued domination of one type over others, nor of the persistency of unimportant characteristics, nor of the inheritance of disease, which is complicated in many cases by the requisite concurrence of two separate heritages, the one of a susceptible constitution, the other of the germs of the disease. Still less can I enter upon the subject of fraternal characteristics, which I have also worked out. It will suffice for the present to have shown some of the more important conditions associated with the idea of race, and how the vague word type may be defined by peculiarities in hereditary transmission, at all events when that word is applied to any single quality, such as stature. To include those numerous qualities that are not strictly measurable, we must omit reference to number and proportion, and frame the definition thus:—'The type is an ideal form towards which the children of those who deviate from it tend to regress.'

The stability of a type would, I presume, be measured by the strength of its tendency to regress; thus a mean regression from 1 in the mid-parents to $\frac{2}{3}$ in the offspring would indicate only half as much stability as if it had been to $\frac{1}{3}$.

The mean regression in stature of a population is easily ascertained, but I do not see much use in knowing it. It has already been stated that half the population vary less than 1·7 inch from mediocrity, this being what is technically known as the 'probable' deviation. The mean deviation is, by a well-known theory, 1·18 times that of the probable deviation, therefore in this case it is 1·9 inch. The mean loss through regression is $\frac{1}{3}$ of that amount, or a little more than 0·6 inch. That is to say, taking one child with another, the mean amount by which they fall short of their mid-parental peculiarity of stature is rather more than six-tenths of an inch.

With respect to these and the other numerical estimates, I wish emphatically to say that I offer them only as being serviceably approximate, though they are mutually consistent, and with the desire that they may be reinvestigated by the help of more abundant and much more accurate measurements than those I have had at command. There are many simple and interesting relations to which I am still unable to assign numerical values for lack of adequate material, such as that to which I referred some time back, of the superior influence of the father over the mother on the stature of their sons and daughters.

The limits of deviation beyond which there is no regression, but a new condition of equilibrium is entered into, and a new type comes into existence, have still to be explored. Let us consider how much we can infer from undisputed facts of heredity regarding the conditions amid which any form of stable equilibrium such as is implied by the word type must be established, or might be disestablished

and superseded by another. In doing so I will follow cautiously along the same path by which Darwin started to construct his provisional theory of pangenesis; but it is not in the least necessary to go so far as that theory or to entangle ourselves in any questioned hypothesis.

There can be no doubt that heredity proceeds to a considerable extent, perhaps principally, in a piecemeal or piebald fashion, causing the person of the child to be to that extent a mosaic of independent ancestral heritages, one part coming with more or less variation from this progenitor, and another from that. To express this aspect of inheritance, where particle proceeds from particle, we may conveniently describe it as 'particulate.'

So far as the transmission of any feature may be regarded as an example of particulate inheritance, so far (it seems little more than a truism to assert) the element from which that feature was developed must have been particulate also. Therefore, wherever a feature in a child was not personally possessed by either parent, but transmitted through one of them from a more distant progenitor, the element whence that feature was developed must have existed in a particulate, though impersonal and latent form, in the body of the parent. The total heritage of that parent will have included a greater variety of material than was utilised in the formation of his own personal structure. Only a portion of it became developed; the survival of at least a small part of the remainder is proved, and that of a larger part may be inferred by his transmitting it to the person of his child. Therefore the organised structure of each individual should be viewed as the fulfilment of only one out of an indefinite number of mutually exclusive possibilities. It is the development of a single sample drawn out of a group of elements. The conditions under which each element in the sample became selected are, of course, unknown, but it is reasonable to expect they would fall under one or other of the following agencies: first, self-selection, where each element selects its most suitable neighbour, as in the theory of pangenesis; secondly, general co-ordination, or the influence exerted on each element by many or all of the remaining ones, whether in its immediate neighbourhood or not; finally, a group of diverse agencies, alike only in the fact that they are not uniformly helpful or harmful, that they influence with no constant purpose—in philosophical language, that they are not teleological; in popular language, that they are accidents or chances. Their inclusion renders it impossible to predict the peculiarities of individual children, though it does not prevent the prediction of average results. We now see something of the general character of the conditions amid which the stable equilibrium that characterises each race must subsist.

Political analogies of stability and change of type abound, and are useful to fix the ideas, as I pointed out some years ago. Let us take that which is afforded by the government of a colony which has become independent. The individual colonists rank as particulate representatives of families or other groups in the parent country. The organised colonial government ranks as the personality of the colony, being its mouthpiece and executive. The government is evolved amid political strife, one element prevailing here and another there. The prominent victors band themselves into the nucleus of a party, additions to their number and revisions of it ensue, until a body of men are associated capable of conducting a completely organised administration. The kinship between the form of government of the colony and that of the parent state is far from direct, and resembles in a general way that which I conceive to subsist between the child and his mid-parentage. We should expect to find many points of resemblance between the two, and many instances of great dissimilarity, for our political analogy teaches us only too well on what slight accidents the character of the government may depend when parties are nearly balanced.

The appearance of a new and useful family peculiarity is a boon to breeders, who by selection in mating gradually reduce the preponderance of those ancestral elements that endanger reversion. The appearance of a new type is due to causes that lie beyond our reach, so we ought to welcome every useful one as a happy chance, and do our best to domicile and perpetuate it. When heredity shall have become much better and more generally understood than now, I can believe that

we shall look upon a neglect to conserve any valuable form of family type as a wrongful waste of opportunity. The appearance of each new natural peculiarity is a faltering step in the upward journey of evolution, over which, in outward appearance, the whole living world is blindly blundering and stumbling, but whose general direction man has the intelligence dimly to discern, and whose progress he has power to facilitate.

FRIDAY, SEPTEMBER 11.

The following Papers were read:—

1. *Insular Greek Customs.* *By* J. THEODORE BENT.

Reasons why the islands of the Ægean Sea have retained more ancient customs than the mainland: (*a*) from not being overrun by barbarian hordes, (*b*) not blended with Italian rulers, (*c*) leniently treated by Turks.

The customs concerning birth and childhood compared with ancient ones; fate-telling; deleterious influence of Nereids on children; the Nereids compared with ancient myths. The customs concerning death; the poetry of death-wails; the belief in Charon and Hades existing still; the freight-money for the ferryman of the Styx. Instances of burial in the islands. The feasts for the dead; belief in vampires; and other points which can be traced to a remote antiquity.

Love of a modern Greek for personifying the mysterious; a modern Erinnys; the views of an islander on the sun; the month of March.

Parallel cases from industrial life between ancient and modern times; the feast of Bacchus at Seriphos; Dionysos on Naxos; the drunken St. George on Paros; resinated wine.

Some instances from agricultural life of a like nature. Ceremony before the sowing of seed; skins for grain; granaries in the ground; ploughs, hoes, and other articles of agriculture; also names for animals.

2. *On the Working of the Ancient Monuments Act of* 1882. *By* General PITT-RIVERS, *F.R.S.*

3. *American Shell-work and its Affinities.* *By* Miss A. W. BUCKLAND.

In this paper the attention of anthropologists is called to some remarkable works in shell, recently discovered in mounds in various States of North America, as described by Mr. W. H. Holmes in a valuable contribution to the 'Proceedings of the Bureau of Ethnology,' Washington. These shell-works consist not only of beads of various forms and sizes, but also of celts, fish-hooks, clubs and other implements of war and the chase; bracelets, pins, crosses of various forms, and more particularly of masks and elaborately engraved gorgets, the ornamentation upon which seems to bear some religious or astronomical signification. Some of these forms are traced by Mr. Holmes to ancient Mexico, and Miss Buckland points out that not only are almost all the forms, both of implements and ornaments, to be found in islands of the Pacific, but also that some of the peculiar symbols engraved upon the ancient American gorgets re-appear slightly altered on shell gorgets in the Solomon and Admiralty Islands, and also on the great drum from Japan exhibited this year at South Kensington. From this, and from the record of a Peruvian vessel laden with merchandise having been met far out at sea by the Spanish navigators, it may be inferred that a commerce existed between the islands of the Pacific and the American continent prior to the Spanish Conquest, and that to this may be traced not only the resemblances in the shell ornaments

described, but also the similarity in the games and calendars of Mexico and Japan pointed out by Dr. Tylor, as well as some ethnical peculiarities observed by Mr. Moseley as existing in the Admiralty Islands.

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4. *Note on the Redmen about Roraima.* *By* E. F. IM THURN.

After referring to his already published views as to the inter-relationship, origins, and classification of the various tribes of Redmen now in Guiana, the author dwelt specially on the places to be assigned in this classification to the Partamonas, Macoosis, and Arekoonas, the three tribes through whose territory he passed on his way to Roraima. Next he briefly detailed the route followed by him on that journey, with special reference to the anthropological facts noted by the way. This was followed by remarks on various special anthropological points; on the curious isolation of the one tribe from the other, and even in some cases of one part from another part of the same tribe; on certain survivals which he noticed of habits of the stone age, such as the persistent manufacture of stone implements and the retention, to some small extent, of the art of engraving pictures on rocks. Finally, a detailed account was given of certain games or dances which had been performed by the Macoosis for the amusement of the author, chiefly rudely dramatic representations of the doings of various animals and birds, together with a few representing impressive events which happen, but happen only rarely, in the lives of the players.

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5. *A Game with a History.* *By* J. W. CROMBIE, *M.A.*

As children in their play generally imitate something they have observed to be done by their elders, and a game once introduced is handed down from generation to generation of children long after its original has ceased to exist, many innocent-looking children's games conceal strange records of past ages and pagan times; hence the importance of the study of this apparently frivolous subject is now fully recognised by anthropologists.

The game of 'Hop-Scotch' is one of great antiquity, having been known in England for more than two centuries, and is played all over Europe under different names. Signor Pitré's solar explanation of its origin appears improbable, for it would require the original number of divisions in the figure to have been twelve, whereas a considerable body of evidence can be adduced to show that it was seven.

It would seem more probable that the game at one time represented the progress of the soul from earth to heaven through various intermediate states, the name given to the last court being most frequently Paradise or an equivalent, such as Crown or Glory, while Purgatory, Limbo Rest, &c., occur as names of the other courts, which corresponds with the eschatological ideas prevalent in the early days of Christianity. Some such game existed prior to Christianity, and the author considers that it has been derived from several ancient games; possibly the strange myths of the labyrinths may have had something to do with 'Hop-Scotch,' and a variety of the game is played in England and France, upon a figure almost identical with that of a game described by Pliny as being played by the boys of his day.

The author believes that the early Christians adopted the general idea of the ancient game, but they not only converted it into an allegory of heaven, with Christian beliefs and Christian names, they Christianised the figure also; abandoning the heathen labyrinth they replaced it by the form of the Basilicon, the early Christian church, dividing it into seven parts, as they believed heaven to be divided, and placing Paradise, the inner sanctum of heaven, in the position of the altar, the inner sanctum of their earthly church.

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6. *The Rule of the Road from an Anthropological point of view.* *By* Sir GEORGE CAMPBELL, *K.C.S.I.*

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7. *On the Modes of Grinding and Drying Corn in old times.* *By* Miss JEANIE M. LAING.

In the lands of Tillyfour, in Aberdeenshire, are the ruins of an old hamlet, with straw kiln attached. Those kilns were used for drying corn before sending it to the mill. The kiln was conical in shape, joists called cabers were laid across, some distance from the ground. Above these were roughly hewn saplings called simmers. On top of these was spread straw, and on the straw was laid the corn. A fire was kindled on the ground, and the heat ascending, dried the corn. A stone called a sparker was placed above the fire, to catch the sparks. In spite of this precaution, the kiln sometimes took fire. When dry, the corn was put into a place called a 'dry corn bed.' When quite cool it was 'riddled' and sent to the mill. At an earlier period corn was ground between two millstones, with an iron rod by way of a handle. This primitive 'mill' was called a quern, and was generally turned by two females, as in Eastern lands. In later times querns were used for grinding malt. Straw kilns have not been in use in Aberdeenshire for nearly a century.

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8. *The Flint-knappers' Art in Albania.* *By* A. J. EVANS.

The author exhibited some Albanian gun-flints and strike-a-lights, partially cased in ornamental lead sheaths studded with glass gems, and described the method now adopted by the Albanian flint-knappers for producing these highly finished implements. The flints were obtained from a range of hills distant about two hours from Joannina, and were mostly of tabular shape, scattered in profusion about the summit of a limestone plateau, but there were no signs of their having been used for manufacture in ancient times, nor have any flint implements of prehistoric date been found either in Epirus or Albania, though several polished stone axes of diorite and other materials have come to light. At present the chief site of flint-knapping industry is Valona and its neighbourhood, and in this case the flints are collected on the Acroceraunian mountains.

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9. *The Discovery of Naukratis.* *By* W. M. FLINDERS PETRIE.

The work of the Egypt Exploration Fund which I have carried on in the first half of this year has brought to light the remains of the city of Naukratis, the great emporium of the archaic Greeks in Egypt. Though often sought for by travellers, no proof of its position had been obtained until I visited the mounds of Nebireh, about five miles from Teh el Barūd station on the Cairo and Alexandria Railway. No archæologist had seen the place before, and I only heard of it by inquiring of Arab dealers. Here I found a decree of the city of Naukratis, a coin of that city of an unknown type, and innumerable remains of the archaic period which agree closely with the historical accounts of the place.

Omitting all questions which relate only to art and architecture, we will briefly note the results which are of more general and scientific interest.

Naukratis was essentially a commercial and manufacturing centre of the Mediterranean trade during the early Greek period. The commerce is repeatedly mentioned by historians, and is amply proved by the great number of ancient weights of the different standards that are found: in six months my collection of weights rose to four times the whole number of Egyptian weights yet known and published, and double the number of Babylonian, while the Attic weights are about half the number yet known from Greece and other countries. The manufacturing importance of the place is shown by the various trades of which the remains were found. Ironworks flourished here as early as the middle of the sixth century B.C.—quantities of ore, of slag, and of finished tools of various kinds show this. Copper was also worked, the ore, slag, and finished objects remaining here. A silversmith's store of dumps of melted silver and early Greek coins yet unmelted was also found. Potteries existed on a large scale; the kilns

still remain, the thick strata of burnt earth thrown away in clearing them, and a great amount of pottery of a style not known elsewhere. Glazed ware was also made here, and large quantities of Greek imitations of Egyptian scarabæi and the moulds employed in making them; such scarabæi were exported to Greece, and are often found in early Greek tombs. Shell-working was also practised, and it is probably to Naukratis that we should attribute the carving of the Oriental *Tridacna* shells, usually attributed to the Phœnicians. Of the trade in later times, after Alexander, the immense quantity of amphora handles with names from Rhodes, Knidos, &c., are good witnesses.

On the history of Greek writing light is also obtained, and we see that as early as the beginning of the sixth century B.C. writing was almost universal on the hundreds of bowls and vases dedicated in the temples, fragments of more than two hundred such inscriptions having been found in clearing the rubbish-hole of the archaic temple of Apollo; among them one by the traitor Phanes which can be dated within a few years of 540 B.C. The majority, however, are earlier than this.

The history of Greek ornament is also illustrated, and we may trace the lotus pattern of Egypt, serving as the basis on which the Greeks developed their honeysuckle ornament with the aid of the Assyrian tree pattern.

In short, we see here the Greeks, with a versatile and highly plastic nature, rapidly developing their arts and manufactures upon the models of the old civilisation of Egypt.

Another, and very different, interest is afforded by the illustration of Egyptian ceremonial at the foundation of their great buildings. For the first time the series of ceremonial deposits has been found, and we see the models of the vases for the libations, the cups for offerings, and the sacrificial instruments of the ceremony; the models of the tools used on the building—the hoe, mortar-rake, adze, chisel, hatchet, trowel, and marking-pegs; the samples of all the materials—mud-brick, glazed pottery, agate, jasper, lapis-lazuli, turquoise, and obsidian; the metals—gold, silver, lead, copper, and iron; and the founder's name—Ptolemy II.—engraved on lapis-lazuli. A model mortar and pair of corn-rubbers accompanied these deposits, and may refer to some unknown ceremony, or to the purpose of the building.

The large collection of objects found will be distributed among public collections, the most important going to the British Museum.

SATURDAY, SEPTEMBER 12.

The Section did not meet.

MONDAY, SEPTEMBER 14.

The following Papers and Report were read:—

1. *On Ancient Tombs in the Greek Islands. By* J. THEODORE BENT.

The study of tombs in the Greek islands is conducive to a knowledge of ancient and forgotten lines of commerce. There are two periods in which the islands seem to have been especially used as depôts for trade:

1. The prehistoric period. Tombs at Antiparos; why this island is especially favourable for this study; nature of the tombs; the marble; obsidian pottery and jewellery finds; speculative remarks as to the date of this race which first peopled these islands.

2. The historic period. Rock-cut tombs on Karpathos; the commercial town of Bourgounta and its favourable situation for commerce; the various descriptions of rock-cut tombs to be found there, and the class of things found in them.

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2. *A New Cave Man of Mentone.* *By* THOMAS WILSON.

In February 1884 there was discovered in one of the famous caverns at Mentone in the Alpes Maritimes, France, a skeleton of one of the ancient and original inhabitants, believed to have belonged to the paleolithic age. It is the purpose of this paper to give some of the details of the discovery, and offer some suggestions concerning the epoch to which the man belonged.

The caverns at Mentone are nine in number. They are nearly alike in their form, general character, and appearance. They are all in the same rock, with the same exposure or outlook, at the same level, belong to the same age, and were doubtless occupied at the same time. They form together a sort of prehistoric village, and their characteristics and evidence are not to be taken separately and isolated, but together and as a whole, making an aggregate testimony which gains momentum with each discovery.

The New Cave Man of Mentone.—Monsieur Rivière's discovery, and the name, 'l'homme de Menton,' by which it has been known, induces me to give this name to this discovery.

The excavations were made during the winter of 1883–4 by Monsieur Louis Julien, of Marseilles, and at his expense, aided by the advice of Monsieur Bonfils, Curator of the Museum at Mentone.

He employed four or five men continuously during the entire winter.

This cavern is marked on Monsieur Rivière's chart as No. 5, but is known in the neighbourhood as No. 4—'*la quatrième grotte.*'

It had been searched many times before, and about 9 or 10 feet in depth had been removed from the original surface, which, however, was plainly marked by a large piece of brèche which still adhered to the perpendicular side wall.

The formation of the floor of the cavern and the process of its filling up presented all the usual evidences of human occupation and industry: charcoal, burnt earth and ashes, hearthstones, split and broken bones of animals (estimated to the number of 15,000 pieces), flint instruments, chips, nuclei, &c., &c., were found in sufficient number, quantity, and distribution, to indicate an indefinitely long occupation.

No morsel of pottery was found, nor were any of the stone implements polished.

At the depth (from the original surface) of 8 mètres 40 centimètres was found the skeleton of this 'new cave man of Mentone.' He was laid on his back with his limbs extended, and had for funeral equipments three large chips of flint (*éclats de silex*) 6 or 7 inches long and 2½ inches broad, in the form of the largest scrapers, placed one on each shoulder, like epaulettes, and one on the brow. *It appeared to be an interment.*

This became more evident when it was found that the body was placed in a sort of natural vault or tomb, formed on one side by the wall of the cavern, and on the other by an immense block of stone with an overhanging edge, which reached to a line perpendicularly over the centre of the skeleton. This placing of the body required an excavation between these rocks of 3 or 4 feet in depth.

The skull was broken into sixty fragments by the pick of the workman; it was carefully taken up and put together by Monsieur Bonfils, and is now exposed in the Museum at Mentone. This was a fortunate accident, for while the rest of the skeleton was being exhumed a quarrel broke out as to the ownership, which ended in the theft and utter destruction of all that remained.

Observations.—Differences in the reports of the depth at which Monsieur Rivière's skeleton was found may be reconciled by suggesting the misapplication or misunderstanding of mètres and feet. He has reported the depth at 6 mètres and a fraction. It has been reported in English 6 feet and a fraction. Its

depth from the original floor was without much doubt about 6 mètres (20 or more feet).

Professor Boyd Dawkins believes these caverns to be of 'doubtful antiquity.' I suppose he means their occupation by man to be of doubtful antiquity. He asserts there is nothing to show that the earth has not been disturbed down to the layer at which the skeletons were found; and Monsieur Mortillet classes Monsieur Rivière's *l'homme de Menton* as neolithic, because of the interment and of the bone *poinçon* and shell beads found with him.

The new discovery dissipates all idea of disturbance, for while *disturbance* might exist for one or two, or even five or six feet, to the depth of twenty or thirty feet it would be impossible.

It must be conceded that the human industry, as manifested by the objects found in these caverns, indicates their occupation during the paleolithic age, for of the thousands found all bear the impress of that age, while none denote particularly the age of polished stone.

To say that the interment belongs to an occupation subsequent to that indicated by the implements found in the cavern, means an interment made by a subsequent race, and consequently made from the then surface or floor of the cavern. This would require a grave to be dug by the neolithic man with his fingers, his stone hatchet, or his deer-horn pick, to a depth of from 6 to 9 mètres, or 20 to 30 feet. This, in earth packed hard and solid, filled with sharp stones, flint chips and implements, and bone splinters, may be regarded as improbable, if not impossible.

It took Messieurs Rivière and Julien, with a full corps of trained and paid workmen, working under an overseer, and armed with all modern implements, steel picks and shovels, barrows, &c., from one to three months' steady work to arrive at the same depth.

That there was an interment would seem to be undoubted, but it was made from a reasonable depth, and was sufficient to serve the purposes of protection and safety of the body. A 'reasonable depth' say from three to eight feet for this purpose would seem to indicate the occupation and industry of that people to which the deceased in his lifetime belonged. This is clearly paleolithic, and not neolithic—is, in fact, the Madélienne époque of Monsieur de Mortillet, if not earlier, and approaching the Moustérienne.

The occupation of this country by prehistoric man would seem to be divided into three zones or belts:

1. On the border of the sea, by the paleolithic man. Possibly the glaciers prevented his occupation farther inland, or destroyed the evidence of it, if any existed.

2. On the heights, and inland for a few miles, by the neolithic man, where are to be found pottery, flint, and in some places bronze.

3. All that country farther inland and among the mountains, in which, as yet, none or very few prehistoric remains of any age have been found.

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3. *Happaway Cavern, Torquay.* *By* WILLIAM PENGELLY, *F.R.S.*, *F.G.S.*

Happaway Cavern occupies the south-western slope of a *Devonian* limestone hill bounding the principal street of Torquay, and is about 200 feet above the sea. It was discovered in October 1862 by quarrymen breaking into it in the ordinary course of their work, and, at the request of the late Lord Haldon, the proprietor, the author undertook its exploration in June 1863, when he performed the manual labour with his own hands in order to eliminate all possibility of doubt respecting the genuineness, as well as the exact positions and associations, of such objects of interest as might be found.

The cavern, when completely emptied in 1866, proved to be about 46 feet long, from 10 to 15 feet broad, and 10 feet high. There was no stalagmitic floor, nor

any satisfactory indication that there ever had been one. The deposit was usually divisible into three zones:—

First, or uppermost.—Fine friable earth, of light chocolate colour, rather dry, containing bones and bits of charred wood, but very few stones. Extending from the surface to about six inches below it.

Second.—Moist tenacious earth, of dark colour, containing bones and bits of charred wood, stones lying at all angles, and commonly angular but occasionally rounded. From 6 to 24 inches below the surface.

Third, or lowermost.—Coarse earth, of somewhat bright red, and rather sandy, differing from the higher zones by the presence of larger and more numerous stones, with occasional blocks of limestone and pieces of stalagmite, while charred wood and bones were less plentiful.

The objects of interest met with were a few marine shells, numerous terrestrial shells, one joint of the vertebral column of a fish, a few bones of birds, bones of badger (very numerous), deer, fox, pig, sheep, hare, rabbit, small rodents, bat, two teeth of bear, parts of two teeth of rhinoceros, one tooth of hyæna, a lower human jaw, and parts of two human skulls.

There were also a few human industrial remains, including charred wood, an infra-human skull artificially divided, about fifty flint flakes and chips, and two groups of miscellaneous objects taken in by rats or other small animals, and including scraps of paper—many of them printed, bits of cord, very fine wood-shavings, and pieces of ribbon.

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4. *On the Human Remains found in Happaway Cavern, Torquay. By* J. G. Garson, *M.D.*

Dr. Garson stated that the bones submitted to him by Mr. Pengelly from Happaway Cavern consisted of the greater part of a cranium, a mandible, and some fragments of the cranium of a child. The bones afforded no indication of being of great age. The cranium was mesaticephalic, and was distinctly different from either the Long or Round Barrow types, indeed, it presented mixed characters, and was such as might be found in any modern graveyard.

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5. *On Three Stone Circles in Cumberland, with some further observations on the relation of Stone Circles to adjacent hills and outlying stones. By* A. L. Lewis, *M.A.I.*

The author referred to a paper read by him at the York meeting, in which he had shown that in eighteen circles in England and Wales there was a marked preponderance of outlying stones or prominent hills towards the N.E., and that the line S.W. to N.E. was specially characteristic of circles, in opposition to the line N.W. to S.E., which was most usual in stone chambers. He then described three circles in Cumberland, bringing forward evidence as to some outlying stones not, so far as he knew, previously noticed, and showed that these circles conformed to the rule already laid down, and that, whereas the Egyptians and the Babylonians followed different rules of orientation, the circle builders followed the Babylonians rather than the Egyptians—a fact which might ultimately be found to have some anthropological importance. After mentioning various facts bearing upon the subject generally, and giving a notable instance of a connection between the temple of another religion and a hill at some distance from it, Mr. Lewis said that in the relation between stone circles and adjacent hills and outlying stones suggestions might be found not only of sun worship, but of mountain worship and phallic worship, not all of which would, however, necessarily have been obvious to every worshipper in the circles.

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6. *The Archæological Importance of ancient British Lake-dwellings and their relation to analogous remains in Europe.*[1] *By* R. Munro, *M.A., M.D.*

Dr. Munro commences by giving a short introductory notice of the discovery and investigation of the crannogs of Ireland and the lake-dwellings of Central Europe. He then gives a *résumé* of the more recent explorations made among the crannogs of Scotland and the remarkable objects recovered from them. From a comparative examination of these relics with other collateral antiquities of the Celts, he arrives at the conclusion that the lake-dwellings of Scotland were essentially the product of Celtic genius, that they were constructed for defensive purposes, and that those in the south-west parts of the country attained their greatest development in post-Roman times, after Roman protection was withdrawn from the provincial inhabitants, and they were left single-handed to contend against the Angles on the east and the Picts and Scots on the north. Having established the Celtic origin of the crannogs of Ireland and Scotland, Dr. Munro proceeds to inquire if there is any ancestral relationship between them and the lake-dwellings of Central Europe. Taking into account the recent discovery of lacustrine abodes in the Holderness, and the few previous records of their existence in Wales and other parts of England, together with the statement of Cæsar that the Britons were in the habit of making use of wooden piles and marshes in their defensive works, he thinks that such indications are not merely solitary instances, but the outliers of a widely distributed custom which prevailed in the southern parts of Britain at an earlier date than that assigned to the crannogs of Scotland. Hence he suggests the theory that the British Celts were an offshoot of the founders of the Swiss lake-dwellings, who emigrated into Britain when these lacustrine abodes were in full vogue, and so retained a knowledge of the custom long after it had fallen into desuetude in Europe. On this hypothesis it would follow that subsequent immigrants into Britain, such as the Belgæ, Angles, &c., being no longer acquainted with the subject, would cultivate new and perhaps improved methods of defensive warfare; whilst the first Celtic invaders, still retaining their primary notions of civilisation, when obliged to act on the defensive would naturally have recourse to their inherited system of protection.

In support of this hypothesis the author points out that the geographical distribution of lake-dwellings, so far as they are known in Europe, closely corresponds with the area formerly occupied by the Celts; that no lake-dwellings have been yet found either in the northern or southern parts of Europe, though the topographical and hydrographical conditions of these regions are not unfavourable for such structures; that the *fascine* dwellings in Europe were identical in structure with the crannogs; and that, though the pile-dwellings were not largely used in the British Isles, the principles on which they were built were not unknown, their disuse being due to topographical and other considerations. Finally, he argues that the wideness in the chronological gap which is supposed to separate the crannogs from the lake-dwellings of Europe is more apparent than real, as the latter existed during the Roman occupation of Gaul, and in one instance at least the custom survived to about the tenth century.

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7. *The Stone Circles in Aberdeenshire, with special reference to those in the more Lowland parts of the County, their Extent and Arrangement, singly or in groups, with General Observations. By the* Rev. James Peter, *F.S.A. Scot.*

The main object in this paper is to draw attention to and put on record the existence of so many interesting remains of a remote antiquity in this part of Scotland, and chronicle any information which may be deemed important as throwing light on a subject admittedly dark and obscure.

[1] See by the author, *Ancient Scottish Lake Dwellings (or Crannogs)*, with a supplementary chapter on Lake Dwellings in England; Edinburgh, David Douglas. Also *Journal of Anthropological Institute* for 1886.

The stone circles of Aberdeenshire, over thirty in all extant, are spread across the county, but the author's observations are confined mainly to the group in the parish of Deer.

They extend over a wide area, appearing now singly, now in groups. For long there would appear to have been no disturbing cause affecting their removal, but since the impulse given to agriculture some sixty to seventy years ago, this destruction has been lamentably frequent.

As to the arrangement: Putting aside the isolated circles, it may be stated that they arrange themselves generally in a group of three, as in the case of Newton, Lonmay, &c. The great exception to this is the large group of circles in the parish of Deer, or Old Deer, as it is now generally called, comprising an area of 25,711 acres imperial, or about 40 square miles. This group consists of seven circles more or less complete. It occupies the centre of the large district of Buchan, or north-eastern division of Aberdeenshire. The circles, including those still subsisting in part as well as those now extinct, stretch in a line almost due north and south, ten miles in length, from Strichen on the north border of the parish, to the hill of Skelmuir on the south. They are all of the same character, with a single exception, and placed on the summit of one or other of the secondary knolls, not generally exceeding 350 feet, which diversify the surface of the parish. A certain regularity attaches to their position, indicating design on the part of those who erected them, while an examination of them singly, in reference to their contiguity, proves that the chain was so constructed that each link was visible from the nearest, and also that thus by a zigzag glance communication was established from one to the other. This assertion has been verified by actual and careful observation.

As to the measurements of the circles generally: Taking seventeen of the most complete in the county, it is found the average diameter is 54 feet, number of stones that composed the circle 12, average height of the largest individual stones 7 feet, distance between the monoliths $13\frac{1}{2}$ feet. In the case of all save three of the circles the altar-stone is on the south meridian, but in the exceptions it faces the N.E. Of the extant and comparatively complete circles, the one at Aikybrae or Parkhouse, and the other at Strichen, have a similar arrangement and character. Both altar-stones have their top flattened with a slope towards the east, and are fixed in position by two stones in the shape of wedges on either side, but not opposite, having an opening underneath sufficient to admit of a thong or cord being passed. The altar-stone in the Parkhouse one is specially mentioned by Colonel Forbes Leslie, and its size given as length $14\frac{1}{2}$ feet, breadth $5\frac{1}{2}$, and depth $4\frac{1}{2}$ feet, its gross weight exceeding 21 tons. A third circle, that known as the Loudon-wood circle, differs from the Parkhouse one, $2\frac{1}{2}$ miles distant, in the matter of the altar-stone and side altar-stones, though not in the enclosing stones. The altar-stone is not flat but ridgy, while each of the side-stones seen in profile towards it presents a very perfect crescent or curve, which, extended on both ends until they met, would form a pretty perfect circle with its centre in the middle of the altar-stone. It is evident that this was no haphazard arrangement, but one of purpose, be that purpose what it may. There is one other circle in the group so different from the others that it demands special notice, viz., the White Cow circle. Here there is no recumbent or altar-stone, but the circle is formed of small irregular stones placed close together and in most cases half buried in heath. In the centre, or rather on the corner of the N.E. quadrant, if we divide the circle by lines from N. to S. and E. to W. passing through the centre, is placed a dolmen, the table stone of which, once supported by five stones, one on the E., two on the N., with two on the S., has been lowered at the open end by the forcible removal of one of its northern supports. As the direction of the table-stone seemed not to be towards any cardinal point of the compass, I resolved to ascertain its actual position, and careful observation has brought out the important fact that a line drawn along the centre lengthwise from W. to E., and projected to the horizon, would strike it as near as may be at 47° north of E., or at the rising of the sun on Midsummer Day. The latitude of Deer being 57° 34′ N., sunrise on Midsummer Day would occur at about 47° 41′ north of E.

The multiplication of these stone circles, and specially in the north-eastern part

of Aberdeenshire, as at Deer, may be assumed as pointing to the existence of a considerable population in early times, and if colonisation came from the east, and possibly Scandinavia, the most easterly point of Scotland would naturally be one of the earliest objective points. Leaving the inhospitable shore, where now stands the flourishing port of Peterhead, the new comers would move on up the valley of the Ugie in search of shelter, where they would find it in a district protected from the cold north by moderately high rounded hills, clothed as tradition asserts, and the mosses prove, by the friendly oak and hazel. That a large population must at an early period have here existed is attested by the numerous cairns and tumuli that extend on either side the river towards the west, while scarcely a height but retains the remains of some rath or circle within which dwelt the inhabitants with the Maormohr or chief.

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8. *Stone Circles in Aberdeenshire.* *By* JOHN MILNE, *M.A.*

Biffie circle in Deer is a good example. It is 50 feet in diameter and is made up of one large horizontal block and ten erect pillars, some now fallen, connected by a low wall. The largest stones, as usual in such circles, are placed on the south side and the smaller on the north. The best stones at command were always taken, but any stone, though not a foot in height, served when better could not be got; they are mere place-markers. What would these stones tell us if we could understand their language, for they are evidently speaking to us? They were not places for defence. Some are on hill-tops, but others on hill-sides commanded by higher ground. Nor for worship; they are numerous in some places and not found at all in other places; no sanctity attached to them for long. One may be seen encroaching on another whose pillars are still standing. Probably they were places of sepulture prepared by kings and chiefs during their lifetime, to be occupied by them after death. One circle had inside the outer row of pillars a large closed chamber filled with gravel, and on the centre of the floor was an urn. On the death of the builder his ashes had been carried into the chamber by a low covered way, and then gravel had been poured in by an aperture at the top. It is not to be wondered at that urns and bones are seldom found in them. Ancient graves in Aberdeenshire are usually shallow, often not a foot deep, merely a small hole into which the ashes of a body burned beside it had been put, with a few small stones for a covering. The graves in the circles had probably been rifled long ago, and had also been subsequently examined repeatedly in search of valuables. The round tower of Mousa, in Shetland, had been perhaps a tomb; it is not suited for defence. The great group of circles in Nairn had probably been erected by the line of Pictish kings who were reigning at Inverness about the time of Columba's visit, and the circles in Deer may with much probability be regarded as the tombs of the mormaers of Buchan, mentioned in the Book of Deer. There is a certain similarity between the Scottish and English circles. Like the northern circles, Stonehenge has the horizontal stone on the south, and round it stood the trilithons, the loftiest to the south.

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9. *Notes on a recent Antiquarian Find in Aberdeenshire.* *By* Dr. F. MAITLAND MOIR.

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10. *The Picts and Præ-Celtic Britain.* *By* HYDE CLARKE.

In preparing a paper for Aberdeen, Mr. Clarke, being desirous of its having a local bearing, chose the question of the Picts. This he proposed to deal with in reference to the inquiries of himself and others as to the præ-Celtic inhabitants of Britain. In continuing his own investigations, he set aside the distinct Basque hypothesis, and treated the influences historically and topographically traceable as Iberian in a wider sense. The Picts have presented a difficult problem, the materials relating to which have been most ably dealt with by Dr. Skene, in his edition of the Chronicles of the Picts. His ultimate conclusion was that the Picts

were, in all probability, non-Celtic, and at the same conviction Professor Rhŷs has arrived, and also at the opinion they were Turanians. Dr. Skene found that the Pictish kings did not succeed from father to son, confirming the statement of Beda that there was a female succession. The male succession begins with Malcolm Canmore. Dr. Skene found that out of forty-two names of Pictish kings a score were of the types of Talarghan, Talan, Taran, &c.; about a quarter Brude, and about a quarter Drust. As these are non-Celtic there is a ground to seek for them in Iberian names, as in the names of the rivers, cities, and southern British kings. The names of kings have to be sought in the heroic epoch precedent to the adoption of Hellenic names. They are to be found in the forms Telegonus, Telkhines, Telkhis, &c., being of the model of Tarkon and Tarkondimotos. So Brude is found under similar circumstances as Proteus, Prœtus, &c., and Drust as Adrastus, &c. In the heroic epoch these three names are found in connection. Brude is the same name as the Brutus, King of Britain, of Geoffrey of Monmouth, whose fables sometimes transmit traditions and sometimes by chance afford parallels to other traditions. Dr. Skene, Professor Rhŷs, and Mr. Grant Allen have pointed out the peculiar relations of the Picts to the Cymric Britons, their late acceptance of Christianity, their retention of a peculiar language, and their bearing towards the Danish invaders. These and other circumstances are explained by considering the Picts as representing the Iberian populations of Britannia and Hibernia, closely pressed by the Celtic invasion and making their last stand in Caledonia among kinsmen. The Picts were as much reviled by the British historians, Gildas and Nennius, as were the Saxons. The Pictish language dying out left a readier opening for the spread of English in Caledonia, the adoption of which was resisted in Wales and in Cornwall. Dr. Skene stated that the husbands of the Pictish mothers of the kings must in some cases have been foreigners, and he traced the case of Eanfrid, son of a king of Northumbria. The advance of knowledge shows us in surviving institutions the nature of exogamy once more widely spread. Under this institution a man or woman cannot marry into the tribe, but into another tribe, while the offspring are held to belong to the tribe of the mother and not of the father. In various historical examples this female succession or matriarchy has been disturbed by male succession, and constantly by Aryan influence. Thus the real explanation of the instance of Malcolm Canmore is that he established the male succession. Mr. Hyde Clarke advocated the collection and preservation of local non-Celtic names in title-deeds and records as a means of affording philological materials.

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11. *Report of the Committee for investigating and publishing reports on the physical characters, languages, and industrial and social condition of the North-western Tribes of the Dominion of Canada.*—See Reports, p. 696.

TUESDAY, SEPTEMBER 15.

The following Papers were read:—

1. *Notes on the opening of a Cist, in the Parish of Leslie, Aberdeenshire. By the* Rev. JOHN RUSSELL, *M.A.*

The parish of Leslie is intersected by the Gadie. It seems to have had a large population at a very early date. It is rich in prehistoric remains, though in the course of agricultural improvements many have disappeared. In the locality are remains of stone circles. Flint spear and arrow heads, stone celts and hammers, whorls and scrapers, have been found in abundance.

The cist to which I refer was found by a farmer in New Leslie when digging sand in a corner of a field. On communicating with me, we examined the place but did not open it up until an opportunity was given to the public to be present.

The cist was on the slope of a ridge lying to the south. The upper part was about three feet below the surface. The sides and cover were of stone slabs of the kind called Correen stone, and had the interstices filled in carefully with fine white clay like putty. This with the site, decomposed granite, had excluded air and moisture.

The contents were a skeleton of which the large bones were complete, and also the skull, which contained all the teeth regular but worn flat.

There was an earthenware urn ornamented, and below the urn two flint spear heads beautifully worked.

I infer from the cist and contents that there was then a belief in a future state.

(1) The act of burial shows this.

(2) The care shown in constructing the cist and its contents. With rude implements the grave had been scooped out, the stones of the sides and cover had been carried for about six miles.

(3) The skeleton lay east and west, with the head looking to the east.

(4) There was nothing inside the urn. It had probably been filled with food for the deceased.

(5) The weapons. These were to be with him in the happy hunting ground to which it was believed he had been translated.

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2. *Notes on a Cist found at Parkhill, Dyce, in October* 1881. *By* W. Ferguson.

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3. *On the Human Crania and other contents found in short stone Cists in Aberdeenshire. By* Professor J. Struthers, *M.D., LL.D.*

Professor Struthers described the leading features of the bones found in eight short stone cists in Aberdeenshire, exhibiting the bones and giving the conclusions which he arrived at as to the sex, age, and stature of the bodies interred in the cists. Most of the bodies were those of men of good stature. Professor Struthers referred specially to a large-sized urn found in a farm in the parish of Fyvie, and which had been sent by the Rev. Mr. Leslie. The urn had been found in a circular hole, measuring 4½ feet in diameter, which had been made in the ground, and a quantity of peat ashes indicated that cremation had taken place. The bottom on which the urn had been placed was coated over with clay to the depth of two inches, covered with small flat stones. The bottom of the cavity on which the urn rested was 2 feet 5 inches from the surface. The urn was made of clay, unglazed. The bones found in the urn were very much broken up.

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4. *Notice of Human Bones found in* 1884 *in Balta Island, Shetland, by D. Edmonston, Esq. By* Professor J. Struthers, *M.D., LL.D.*

The paper stated that while Messrs. Ritchie and Downie, fish-curers, were erecting a fish-curing station in Balta Island, there was found a number of skeletons. The workmen first came upon one skeleton lying at full length, the bones of which were in perfect preservation. The bones were those of a man over six feet in height. Subsequently other twelve skeletons were laid bare, all complete except one. All the bones were of large size and were those of men. The bodies had not been enclosed in coffins, and they had not been interred with any degree of regularity. Some had been buried on their backs, others on their sides, and two of them face downwards. None of the bodies were found more than eighteen inches below the surface. Professor Struthers said that he had received the bones, which were at present to be seen in the gallery in connection with the Anatomical Museum. There was nothing particular about the skeletons. The bones were all quite fresh. Bones might be in sand hundreds of years, and remain fresh. The bones in question were those of strong men, adolescent and of middle age.

Dr. Struthers concluded by inviting the members to view these urns and bones, arranged in a gallery in one of the anatomical laboratories at Marischal College, and also a number of interesting skulls of various races of mankind, which he had placed there for the occasion. He also mentioned that Aberdeen University was now forming at King's College a museum of archæology, which they hoped would represent the prehistoric remains of man in the north-east of Scotland. As convener of the committee on the movement, he stated that they would be glad to receive all such specimens found in the district.

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5. *Some important Points of Comparison between the Chimpanzee and Man. By* Professor D. J. Cunningham.

Professor Cunningham exhibited some plates of frozen sections of the chimpanzee, which brought out several important points of comparison between it and man.

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6. *Abnormal and Arrested Development as an Indication of Evolutionary History. By* J. G. Garson, *M.D.*

Dr. Garson began by stating that, perhaps, the most fertile source of information regarding the history of man's evolution is derived from a study of his embryological development. Another source from which much valuable information regarding the early history of our own specialisation, and that of other animals, might be gleaned, is Teratology, which had for its domain the consideration of abnormal conditions of development. Many of the conditions included under this branch are of a pathological nature, and due to the effects of disease; others, however, are not—such, for example, as an abnormal and unusual production of normal structures and cases of arrested development. To a consideration of some conditions occurring under one or other of these categories he called attention. The examples which he had selected had come more especially under his own observation. Persons are occasionally found with abnormal development of hair on their bodies. The type mammal was an animal whose body was covered with hair. Under certain circumstances hair may more or less disappear, according to the conditions under which an animal lives. In man it is only feebly developed, except on the head; and in the cetacea or whales it has entirely disappeared, with the exception of a very few bristles near the mouth. Dr. Garson proceeded to explain how universal development of hair takes place in man. In ordinary cases the hair-growing apparatus in the embryo remains stationary, instead of keeping pace with the growth and development of the other organs of the body, with the result that no hairy covering such as is found in other mammals is present, but only short rudimentary hairs appear at intervals. But in some exceptional cases this stationary condition of the hair follicles does not occur, and they go on actively developing with the rest of the body, with the result that a hairy covering is produced. The hairless condition now normal in man has evidently been gradually acquired through a long period of time, as such a change could not take place rapidly and become such a stable condition as it is found to be otherwise.

Abnormal development of fingers occurs sometimes in man, but must be classed entirely apart from such forms of abnormality as had been considered in the hair-growth. Supernumerary digits occurring in animals with a less number of digits than five indicated evolutionary changes in some cases, but in others were due to the same cause as their appearance in man.

In arrested development the abnormal organ or portion of the body, instead of going through the various stages it usually does till it arrives at the condition it normally assumed in the group of animals in which it occurs, stops short at one or other stages. The stage at which it stops may correspond to that which is normal in a lower grade of animal life, and so gives direct evidence that the higher forms of animal life, such as man, pass through and beyond the stages at which the lower stop. It must not be forgotten also that in some respects an

animal of a lower grade may possess specialisations in some structures or organs of a higher ground than animals much higher in the scale of life. Cases of arrested development give us a clue as to how these specialisations occur. It was explained how cases of median harelip in the human subject may correspond to a normal condition in the cat and rabbit, and how abnormal conditions of the nose sometimes occurring in man, indicate how the modification in the nasal organ of the elephant was produced.

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7. *The Symbol Pillars abounding in Central Aberdeenshire. By the* Rev. JOHN DAVIDSON, *D.D.*

The following are the principal points referred to in this paper:—

Peculiar symbols, incised chiefly upon unhewn monoliths, found over the north-east parts of Scotland, but mostly in the centre valley of Aberdeenshire.

Similar prevalence of stone circles. These traceable also along the supposed routes of Celtic migration from Asia.

Relative antiquity of symbol pillars and cross-bearing slabs in the same district of Scotland.

Coincidence in locality of symbol pillars and such inscriptions with ancient Pictish kingdom.

Symbol sculptures not the work of Christian times, or of the Romans, or of the Scots who succeeded the Pictish dynasty.

Certain particulars associating the sculptures with the Pictish people and with eastern Celts.

Hypotheses as to origin and meaning of symbols. Early and important inhabitation of Central Aberdeenshire. Pictish connection.

Remarkable finds in the district.

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8. *Notes on some of the Bantu Tribes living round Lake Nyasa in Eastern Central Africa. By* Dr. ROBERT LAWS.

Lake Nyasa is 350 miles long, varying in breadth from 16 to 60 miles, with 15 different tribes living round it, each speaking a separate language. Best known of these are:—At the north end, the Anachusa coming from a point farther northward. Round Bandawe are the Atonga, while at Kotakota on the west, and Losewa and Makanjira on the east side of the Lake, are the Swahili and Arabs. To the west of Cape Maclear are Awisa from Lake Bangweolo. Yao, from the sources of the Rovuma, conquered the Anyanja, and are masters of the south part of Nyasa, and the hills to the east of the Upper Chiri River. The Anyanja or lake people lived on the lake shore, and apparently extended far to the north. On the highlands west of Lake Nyasa are the Angoni or Maviti. They came from the banks of the River Umsunduso, and crossing the River Zambezi in 1836, conquered many tribes, broke up into sections, and settled in different places.

The natives are generally well developed physically, but vigour of body and mind is affected by climate and food. Prognathism is not very marked. Umbilical hernia is very common at some places. In walking the natives do not turn out their toes, and the second toe is always longer than the great toe. The reputed keenness of vision and acuteness of hearing of uncivilised tribes is due rather to the contrast between the training of the native and the traveller than to any difference of the organs. In endemic diseases the European constitution resists the onset of the disease longer, but suffers more acutely from such than the native.

The natives depend chiefly on agriculture for subsistence. No traces of a stone age have been found, but there are lake dwellings to be seen. There are iron mines in several places, and copper also is found. The smelting furnaces for iron of the Atembuka are 15 feet high, with eight blast pipes, and in section similar to those employed at home. Canoes consist of hollowed trees. Fishing nets, made of ntingo bark and bwarze fibre, are of different sorts. Hunting is common in certain districts. Dogs are used in following rabbits; nets, pitfalls, spears and guns for larger game.

Clothes are made of the inner bark of a tree, but some wear skins. The manufacture of cotton cloth, on the Chiri, is giving way to English calico. The Anachusa use a mordant in dyeing.

The architecture of the houses is simple. All houses are round, but the different tribes construct them differently. Pottery is the work of the women, and is done by hand. Some of these vessels are very neat. Grain is pounded in wooden mortars, and ground by rubbing between two stones. Their most common dish is a stiff porridge.

Natives measure time by days, lunar months, and years; they thrust a stick into the earth and also use the middle finger of the hand to form rude sundials. Their knowledge of the facts of natural history is surprisingly accurate, and they have names for all the things they see. Their practice of medicine is more the use of charms, but they know some plants with powerful properties. Their ordeal poison bark, called mwave, is the *Erythrophlœum guineense*, which if not vomited causes death. Their most deadly poison for arrows is the gall of the crocodile. They use several emmenagogues, and know to pierce the membranes to produce abortion. Obstetric practice is in the hands of old women, but if nature fails, patients are left to die; yet the Anachusa know how to rectify the malpresentation of a calf. In surgery they know how to set fractures with splints of reeds, reduce dislocations, and bleed by cupping, and by opening the temporal artery. Lacerated wounds they dress with charcoal and oil; an indolent ulcer is treated by scrubbing the surface with the core of a mealie cob.

Slavery is common, but infanticide is not practised. Polygamy is the general custom. Among the Atonga, a girl is often betrothed before she is born. The Angoni give cattle to a father-in-law on marriage, and among them immorality is punished by death.

Land nominally belongs to a chief, but really to a tribe; occupation being the only proof of personal or family possession. For the repression of crime, murder is punishable by death, but blood-money is often accepted. A person attempting to steal, if it is dark, may be killed, but if recognisable must not be so treated. The ordeals in common use are by boiling water and the mwave poison. The government is patriarchal. The plebs have no voice in it; but among the Angoni they use the songs sung at their martial dances to express their political feeling.

All the tribes believe in the immortality of the soul, some in its transmigration. Among the Angoni ancestral worship is the only religious conception; but among the Anyanja there is also the idea of a deity, and among the Anachusa the idea of a Supreme Good and an Evil Spirit. Their folk-lore contains the common Bantu story of the origin of death, and among the Angoni there is a legend of a wooden Tower of Babel.

The languages all belong to the Bantu family. The characteristic of this is the principle of euphonic or alliteral concord, by which the euphonic letter or syllable of the noun recurs in the depending parts of speech in the sentence, thus:—My big cup fell and is broken—*Tshi*ko *tshatshi*kuru *tsha*nga *tshi*nagwa ndimo *tshi*naswedwa, where the concord is marked by italics. The verb is very elaborate, the simple form having a positive and a negative conjugation of the active and passive voices. Secondary and tertiary derivative forms can be made from the simple form, and each of these passes through all the inflections of the simple form. A complete paradigm of the Chinyanja verb would show more than 27,000 different examples of the third person singular. What is the meaning of the word 'savage'?

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9. *Exhibition of the Skeleton of a Strandlouper from South Africa. By* Professor A. Macalister, *F.R.S.*

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10. *A brief Account of the Nicobar Islanders, with special reference to the Inland Tribe of Great Nicobar. By* E. H. Man.

In the interior of Great Nicobar there is a wild race, styling themselves 'Shab Dawá,' of whom as yet little information has been obtainable; they are distinct

from the inhabitants of the other islands and of the villages on their own seaboard, who are of Malay origin, and by whom they are called 'Shom Peṅ' ('Shom' denoting 'tribe,' and 'Peṅ' being the tribal designation).

It appears certain that they are the descendants of a very ancient aboriginal population of Mongolian origin. The first mention that we find of them is from the pen of Pastor Rosen, a Danish missionary, who, while resident at the Nicobar Islands between the years 1831–34, spoke of them, from hearsay, as in much the same degraded condition as we find them at the present day. He said that 'they wear no clothes, possess no houses, live like animals in the depths of the forests, and shun the sight of men, never leaving their lairs except to search for food, which they sometimes steal from such of the coast huts as are temporarily vacated, or occupied only by a few aged or infirm folk whom they are able to surprise or overpower.'

In 1876 and 1881 a few members of this tribe living near the north-east of Great Nicobar were seen by the late Mr. de Röepstorff, who in the latter year accompanied Colonel T. Cadell, V.C., Chief Commissioner of the Andamans and Nicobars, in a visit to their encampments. During the last eighteen months Mr. E. H. Man, while in charge of the Nicobar Islands, has paid six visits to Great Nicobar, on four of which he succeeded in seeing and photographing parties of this tribe, both near Ganges Harbour and on the west coast.

On the first of these occasions (viz., February 1884) two youths, aged about eighteen and fourteen years respectively, were persuaded to leave their friends for seven days, at the end of which they were conveyed back from Nancowry in the settlement steamer. During their visit to Mr. Man they proved themselves tractable and timid, and submitted with a good grace to ablutions which were found very necessary. Although this is the first recorded instance of a Peṅ having ventured from his savage haunts, these lads exhibited the Oriental characteristic absence of wonderment at all the novel surroundings and tokens of civilisation in the Government settlement. They were fair specimens of their race, the members of which are found to be usually well nourished, of good physique, and, while young, favoured with pleasant features. The height of the males appears to range between 5 feet 2 inches and 5 feet 8 inches; their skin is fairer than that of the generality of the coast people, who, on their part, are less dark than the Malay; the hands and feet seem to be decidedly large, and bear evidence of the rough work of their daily lives; the hair, which is straight, is commonly worn uncut and unkempt, and, as habits of cleanliness are manifestly foreign to their nature, its condition can better be imagined than described.

As a result of their friendly intercourse in recent years with the coast people, they have acquired the habit, so universally practised among the latter, of chewing the betel-nut (*Chavica betle*) with or without quicklime, and are consequently beginning to be similarly disfigured with black teeth, though not yet to the hideous extent common among their more civilised, or, rather, less savage, neighbours. They likewise now imitate the latter in respect to clothing, the men adopting the narrow loin cloth and the women a small cloth skirt.

Their dwellings are small, and cannot compare with those of the coast people, and are indeed but little, if at all, superior to those of the Negritos in Little Andaman, but they more nearly assimilate the former in design as well as mode of construction, for they are erected on posts; the floors being raised six or seven feet above the ground necessitate the use of ladders.

It is impossible within the limits of this abstract to make further mention of the dwellings, or to describe the peculiar sack-like cooking vessels of this strange race.

It is, however, worthy of note that the Pen tribes—despite their low state of civilisation—are found capable of expressing high numerals; though the *terms* used are distinct, the *system* is apparently identical with that employed by the coast people.

Mr. Man hopes before long to be able to supplement in many particulars the rudimentary information which has hitherto been obtainable regarding the Peṅ, but the task is one of considerable difficulty, for, apart from the dread entertained by

this tribe towards aliens, their frequent feuds place from time to time a temporary barrier to all intercourse between them and our friends on the coast, through whom at present all our communications have to be conducted. The nearest portion of Great Nicobar island is, moreover, about 60 miles distant from the Government settlement at Nancowry.

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11. *A proposed Society for Experimental Psychology.*[1] *By* JOSEPH JACOBS, *B.A.*

Though this is the age of societies, there is no organised association in England devoted to the interest of the science of mind. Yet there is plenty of scope for such a society. Psychology has itself reached what may be termed the monographic stage, and there are besides several sciences which are independently treating various branches of mental science, *e.g.* neuro-physiology, folklore and analogous branches of anthropology, social statistics and *Völkerpsychologie*, comparative syntax, and the doctrine of insanity. There is thus plenty of work to do, and London University has trained a number of workers. Psychologists had a separate journal (*Mind*); why should they not have a separate society? This would offer the usual advantages of a *local*, library, opportunities of meeting for fellow-students, publication of memoirs, *Jahresberichten*, bibliographies, &c. It would have important work to do in settling the scope, terminology, and divisions of the science. But, above all, there was one particular function which such a society could perform which made its existence more desirable than in any other subject. The members of the society would be made to form its own laboratory: their minds might be utilised as materials on which to work. Full membership might be held to imply readiness to aid in special investigation, by answering queries issued by properly constituted organs of the society. Thus, any member desiring to study comparatively any problem in which introspection was involved, would state his wants to the general committee. This body, if the subject were thought worthy of it, would appoint a sub-committee (to which the member in question would act as honorary secretary) to investigate the matter, and they would be empowered to address specific inquiries on the subject to the members of the society. By this means the chief hindrance to the progress of the science, the subjective and personal character of the results of individual inquiry, would be removed, if such a scheme could be got into working order.

Mr. Galton's experience in his investigations on imagination had shown the practicability of such a method of inquiry. And with regard to the question as to the subjects which lent themselves to such investigations, the difficulty would rather be to pick out the most important from the many which would suggest themselves to trained psychologists. Among many others might be numbered the whole field of psycho-physical research, now developed into a separate branch of psychology by Fechner, Wundt, and others, and the observation of children begun by Darwin and developed by Taine, Perez, Preyer, and others. The collection of actual trains of association, the extent of the field of attention, after-images, colour-blindness and note-deafness, will-practice, how family traits are set, and by whom—these and a hundred analogous topics would receive elucidation by the adoption of this plan. It might be hoped that we might soon be enabled to measure the mental qualities of individuals almost as accurately as we can now measure their physical ones.

As an instance of such an inquiry, which might even deserve the attention of a Psychometric Committee of the British Association, reference might be made to some recent investigations on verbal memory by a German author, Dr. Ebbinghaus. By careful examination of the conditions under which he could reproduce unmeaning words of various lengths, he had been able to deduce quantitative laws for memory. In addition to these, the author of the paper had deduced the following relations from Ebbinghaus' results. There is for everyone a limited number ot unmeaning syllables which he can repeat after one hearing; this number the author

[1] Published *in extenso, Mind.* Jan 1886.

proposed to call 'the threshold of memory.' He had deduced from Ebbinghaus' results that for every syllable over the threshold three repetitions of the word are required to ensure that it be accurately remembered. Thus, a person whose threshold is six syllables would know Shakespeare's longest word, *Honorificabilitudinitatibus,* after repeating it twenty-one times; one whose threshold value was eight could repeat it after fifteen repetitions; and so on. Just at present this curious result was based only on a single investigation. If a Psychological Society were in existence its validity would be at once tested.

The practical utility of such inquiries would be at once evident on reflecting on the gain which would accrue to education if some method could be obtained by which children's minds (*e.g.* their 'threshold of memory') could be measured on entry into school and at various intervals afterwards. And, looking wider, if the art of conduct is ever to be based on scientific grounds, it will be from psychology that it will seek its data. The final end of the British Association itself might be said to be the formation of good characters, and yet such is the chaotic state of psychological investigation that we cannot give even a provisional account of what constitutes a good character, or even define accurately what are the ingredients of character generally. The formation of a Psychological Society on the lines suggested in this paper would certainly do something in advancing these ends and removing these obscurities.

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12. *A Comparative Estimate of Jewish Ability.*[1] *By* JOSEPH JACOBS, *B.A.*

This is a parallel investigation to that of Mr. Galton in his 'Hereditary Genius,' based, as is well known, on an application of the law of error to the data given in dictionaries of contemporary biography. From these Mr. Galton had calculated that in every million of Englishmen over fifty there would be one man of preeminent excellence (class X), 14 of eminent ability (class G), and 233 of ability equal to that of an English judge (class F). By two independent methods the author had ascertained that almost exactly one million Jews had reached the age of fifty in the century 1785–1885. The problem is to find how many of these would be included in the above classes of ability. In all, 335 names of Jewish celebrities had been collected from the various dictionaries of contemporary biography (Cooper, Vapereau, Gubernatis). Of these, 166 were rejected as of fourth-class ability (E), being 10 per cent. more than were rejected in Mr. Galton's investigations. Of the remaining 169, four were classed as X (B. Disraeli, H. Heine, F. Lassalle, F. B. Mendelssohn), 20 as G (Auerbach, Benfey, Börne, Cremieux, E. Gans, A. Geiger, H. Gratz, Halevy, Sir W. Herschel, Jacobi, Sir G. Jessel, Lasker, Lazarus, S. Maimon, K. Marx, Meyerbeer, Neander, J. Oppert, Sir F. C. Palgrave, Rachel, Ricardo, Jules Simon, Steinschneider, Steinthal, Sylvester, Zunc), and 142 as F. The numbers in the first two classes were superior to the results for Englishmen, and would seem to imply superior ability in Jews. The third, however, was far below the normal value, which may be attributed to the restrictions under which Jews have laboured: these would tend to keep down third-class powers more than those of the other two classes. This explanation is confirmed by the numbers of celebrities before and after emancipation in various countries, and especially by the case of Russia, where two-thirds of European Jews live, and which yet contributes only nine names to the list, of whom five were rejected, and the remaining four only reached class F. The general result seemed to be that there was a considerably greater chance of finding distinguished men among a million Jews than among a million Englishmen. But this result has to be modified by the consideration that nearly all Jews live in towns, and the comparison therefore ought to be with the Englishmen of cities.

Turning from the numbers who reach eminence to the subjects in which eminence is reached, the following results were obtained. No Jews were distinguished as agriculturists, engravers, or sailors; fewer Jews, as compared with

[1] Published *in extenso, Journ. Anthrop. Inst.* Feb. 1886.

Englishmen, reached eminence in authorship, divinity, engineering, the army, as statesmen, or as travellers; while more Jews than Englishmen obtained fame as actors, chessplayers, doctors, merchants, metaphysicians, musicians, poets, and philologists. The percentages were about equal for antiquaries, architects, artists, lawyers, scientists, political economists, and sculptors. These results seem to confirm popular impressions, except as regards the equal capacity of Jews for art and science, in which they are generally thought inferior. Among other results deduced from the list, were that Jews of Spanish descent showed greater ability than their German brethren, and that the offspring of mixed marriages showed greater ability than either; the most marked superiority of Jews over Englishmen was in philology, where they numbered ten times as many, and in music, where they showed sevenfold proficiency.

What are the causes which render Jews, though hitherto so hampered in the struggle for fame, capable, to say the least, of holding their own when compared with Englishmen? The following may be mentioned: the intelligence of dissenters generally, their life in cities, their care for education in the past and present, the study of Hebrew as training in linguistics, the undogmatic nature of Judaism, the encouragement given to young men of talent. And it must be remembered that, in the past, every generation has been weeded of its weak-kneed members, who have been tempted or forced to become Christians, so that contemporary Jews are the outcome of a long process of unnatural selection.

It is perhaps unnecessary to add that the present estimate is necessarily one-sided, though every precaution has been taken by the author to remove subjective bias in dealing with this question. At any rate, the results obtained, though favourable to Jews, cannot be regarded as opposed to general impressions.

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13. *Traces of Early Human Habitations on Deeside and Vicinity. By the* Rev. J. G. Michie, *A.M.*

Circular Cairns:—Their structure. Their probable uses—human dwellings; sepulchral purposes. Urns, chests (cists) found in connection (Migvie).

Yerd Houses:—General structure—examples in Cromar, Glenkindy, and Kildrummy. Probable uses. Generally found in the vicinity of round cairns and circular foundations.

Lake Dwellings (Crannogs):—Island in Loch Kinnord, Loch of Leys. Similar to those found in Wigtonshire and Ayrshire. Dr. Stuart's 'Scottish Crannogs,' and Dr. Munroe's 'Ancient Scottish Lake Dwellings.' Relics found in connection—canoes, arrow-heads, celts, stone knives, and stone cups.

Moated Forts:—Lumphanan, Invernochty, Rothiemurchus, and ruder form at Loch Davan.

Ancient Pictish Towns:—Character, and situation. Davan—Short description of; probably the *Devana* of the Romans.

'The information conveyed under the two first headings is, in great part, new; but the general conclusion is not much different from that of previous writers on these subjects.

'The authorities adduced for the observations under the third heading are given in the Abstract. The author's own explorations point very much in the direction of those of previous investigators.

'Under the heading Moated Forts, the writer advocates the more extensive and careful exploration of these remains; and from such he anticipates important elucidation of our early historic period.

'The last heading is an abridged excerpt from the author's work: "History of Loch Kinnord, *D. Douglas*, 1877, pp. 23, 45."'

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[*An asterisk* (*) *signifies that no abstract of the communication is given.*]

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Together with the Transactions of the Sections, Rev. W. Vernon Harcourt's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TENTH MEETING, at Glasgow, 1840, *Published at* 15*s*. (Out of Print.)

CONTENTS:—Rev. B. Powell, Report on the Recent Progress of discovery relative to Radiant Heat, supplementary to a former Report on the same subject inserted in the first volume of the Reports of the British Association for the Advancement of Science;—J. D. Forbes, Supplementary Report on Meteorology;—W. S. Harris, Report on Prof. Whewell's Anemometer, now in operation at Plymouth;—Report on 'The Motion and Sounds of the Heart,' by the London Committee of the British Association, for 1839-40;—Prof. Schönbein, an Account of Researches in Electro-Chemistry;—R. Mallet, Second Report upon the Action of Air and Water, whether fresh or salt, clear or foul, and at various temperatures, upon Cast Iron, Wrought Iron, and Steel;—R. W. Fox, Report on some Observations on Subterranean Temperature;—A. F. Osler, Report on the Observations recorded during the years 1837, 1838, 1839, and 1840, by the Self-registering Anemometer erected at the Philosophical Institution, Birmingham;—Sir D. Brewster, Report respecting the Two Series of Hourly Meteorological Observations kept at Inverness and Kingussie, from Nov. 1st, 1838, to Nov. 1st, 1839;—W. Thompson, Report on the Fauna of Ireland: Div. *Verte-*

brata;—C. J. B. Williams, M.D., Report of Experiments on the Physiology of the Lungs and Air-Tubes;—Rev. J. S. Henslow, Report of the Committee on the Preservation of Animal and Vegetable Substances.

Together with the Transactions of the Sections, Mr. Murchison and Major E. Sabine's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE ELEVENTH MEETING, at Plymouth, 1841, *Published at* 13*s.* 6*d.*

CONTENTS:—Rev. P. Kelland, on the Present State of our Theoretical and Experimental Knowledge of the Laws of Conduction of Heat;—G. L. Roupell, M.D., Report on Poisons;—T. G. Bunt, Report on Discussions of Bristol Tides, under the direction of the Rev. W. Whewell;—D. Ross, Report on the Discussions of Leith Tide Observations, under the direction of the Rev. W. Whewell;—W. S. Harris, upon the working of Whewell's Anemometer at Plymouth during the past year;—Report of a Committee appointed for the purpose of superintending the scientific co-operation of the British Association in the System of Simultaneous Observations in Terrestrial Magnetism and Meteorology;—Reports of Committees appointed to provide Meteorological Instruments for the use of M. Agassiz and Mr. M'Cord;—Report of a Committee appointed to superintend the Reduction of Meteorological Observations;—Report of a Committee for revising the Nomenclature of the Stars;—Report of a Committee for obtaining Instruments and Registers to record Shocks and Earthquakes in Scotland and Ireland;—Report of a Committee on the Preservation of Vegetative Powers in Seeds;—Dr. Hodgkin, on Inquiries into the Races of Man;—Report of the Committee appointed to report how far the Desiderata in our knowledge of the Condition of the Upper Strata of the Atmosphere may be supplied by means of Ascents in Balloons or otherwise, to ascertain the probable expense of such Experiments, and to draw up Directions for Observers in such circumstances;—R. Owen, Report on British Fossil Reptiles;—Reports on the Determination of the Mean Value of Railway Constants;—Dr. D. Lardner, Second and concluding Report on the Determination of the Mean Value of Railway Constants;—E. Woods, Report on Railway Constants;—Report of a Committee on the Construction of a Constant Indicator for Steam Engines.

Together with the Transactions of the Sections, Prof. Whewell's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWELFTH MEETING, at Manchester, 1842, *Published at* 10*s.* 6*d.*

CONTENTS:—Report of the Committee appointed to conduct the co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Dr. J. Richardson, Report on the present State of the Ichthyology of New Zealand;—W. S. Harris, Report on the Progress of Meteorological Observations at Plymouth;—Second Report of a Committee appointed to make Experiments on the Growth and Vitality of Seeds;—C. Vignoles, Report of the Committee on Railway Sections;—Report of the Committee for the Preservation of Animal and Vegetable Substances;—Dr. Lyon Playfair, Abstract of Prof. Liebig's Report on Organic Chemistry applied to Physiology and Pathology;—R. Owen, Report on the British Fossil Mammalia, Part I.;—R. Hunt, Researches on the Influence of Light on the Germination of Seeds and the Growth of Plants;—L. Agassiz, Report on the Fossil Fishes of the Devonian System or Old Red Sandstone;—W. Fairbairn, Appendix to a Report on the Strength and other Properties of Cast Iron obtained from the Hot and Cold Blast;—D. Milne, Report of the Committee for Registering Shocks of Earthquakes in Great Britain;—Report of a Committee on the construction of a Constant Indicator for Steam-Engines, and for the determination of the Velocity of the Piston of the Self-acting Engine at different periods of the Stroke;—J. S. Russell, Report of a Committee on the Form of Ships;—Report of a Committee appointed 'to consider of the Rules by which the Nomenclature of Zoology may be established on a uniform and permanent basis;'—Report of a Committee on the Vital Statistics of Large Towns in Scotland;—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

Together with the Transactions of the Sections, Lord Francis Egerton's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTEENTH MEETING, at Cork, 1843, *Published at* 12*s.*

CONTENTS:—Robert Mallet, Third Report upon the Action of Air and Water, whether fresh or salt, clear or foul, and at Various Temperatures, upon Cast Iron, Wrought Iron, and Steel;—Report of the Committee appointed to conduct the Co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Sir J. F. W. Herschel, Bart., Report of the Committee appointed for the Reduction of Meteorological Observations;—Report of the Committee appointed for Experiments on Steam-Engines;—Report of the Committee appointed to continue their Experiments on the Vitality of Seeds;—J. S. Russell, Report of a Series of Observations on the Tides of the Frith of Forth and the East Coast of Scotland;—J. S. Russell, Notice of a Report of the Committee on the Form of Ships;—J. Blake, Report on the Physiological Action of Medicines;—Report of the Committee on Zoological Nomenclature;—Report of the Committee for Registering the Shocks of Earthquakes, and making such Meteorological Observations as may appear to them desirable;—Report of the Committee for conducting Experiments with Captive Balloons;—Prof. Wheatstone, Appendix to the Report;—Report of the Committee for the Translation and Publication of Foreign Scientific Memoirs;—C. W. Peach, on the Habits of the Marine Testacea;—E. Forbes, Report on the Mollusca and Radiata of the Ægean Sea, and on their distribution, considered as bearing on Geology;—L. Agassiz, Synoptical Table of British Fossil Fishes, arranged in the order of the Geological Formations;—R. Owen, Report on the British Fossil Mammalia, Part II.;—E. W. Binney, Report on the excavation made at the junction of the Lower New Red Sandstone with the Coal Measures at Collyhurst;—W. Thompson, Report on the Fauna of Ireland: Div. *Invertebrata;*—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

Together with the Transactions of the Sections, the Earl of Rosse's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FOURTEENTH MEETING, at York, 1844, *Published at* £1.

CONTENTS:—W. B. Carpenter, on the Microscopic Structure of Shells;—J. Alder and A. Hancock, Report on the British Nudibranchiate Mollusca;—R. Hunt, Researches on the Influence of Light on the Germination of Seeds and the Growth of Plants;—Report of a Committee appointed by the British Association in 1840, for revising the Nomenclature of the Stars;—Lt.-Col. Sabine, on the Meteorology of Toronto in Canada;—J. Blackwall, Report on some recent researches into the Structure, Functions, and Economy of the *Araneidea* made in Great Britain;—Earl of Rosse, on the Construction of large Reflecting Telescopes;—Rev. W. V. Harcourt, Report on a Gas-furnace for Experiments on Vitrifaction and other Applications of High Heat in the Laboratory;—Report of the Committee for Registering Earthquake Shocks in Scotland;—Report of a Committee for Experiments on Steam-Engines;—Report of the Committee to investigate the Varieties of the Human Race;—Fourth Report of a Committee appointed to continue their Experiments on the Vitality of Seeds;—W. Fairbairn, on the Consumption of Fuel and the Prevention of Smoke;—F. Ronalds, Report concerning the Observatory of the British Association at Kew;—Sixth Report of the Committee appointed to conduct the Co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Prof. Forchhammer on the influence of Fucoidal Plants upon the Formations of the Earth, on Metamorphism in general, and particularly the Metamorphosis of the Scandinavian Alum Slate;—H. E. Strickland, Report on the Recent Progress and Present State of Ornithology;—T. Oldham, Report of Committee appointed to conduct Observations on Subterranean Temperature in Ireland;—Prof. Owen, Report on the Extinct Mammals of Australia, and descriptions of certain Fossils indicative of the former existence in that continent of large Marsupial Representatives of the Order Pachydermata;—W. S. Harris, Report on the working of Whewell and Osler's Anemometers at Plymouth, for the years 1841, 1842, 1843;—W. R. Birt, Report on Atmospheric Waves;—L. Agassiz, Rapport sur les Poissons Fossiles de l'Argile de Londres, with translation;—J. S.

Russell, Report on Waves;—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

Together with the Transactions of the Sections, the Dean of Ely's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTEENTH MEETING, at Cambridge, 1845, *Published at* 12*s.*

CONTENTS:—Seventh Report of a Committee appointed to conduct the Co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Lieut.-Col. Sabine, on some Points in the Meteorology of Bombay;—J. Blake, Report on the Physiological Actions of Medicines;—Dr. Von Boguslawski, on the Comet of 1843;—R. Hunt, Report on the Actinograph;—Prof. Schönbein, on Ozone;—Prof. Erman, on the Influence of Friction upon Thermo-Electricity;—Baron Senftenberg, on the Self-registering Meteorological Instruments employed in the Observatory at Senftenberg;—W. R. Birt, Second Report on Atmospheric Waves;—G. R. Porter, on the Progress and Present Extent of Savings' Banks in the United Kingdom;—Prof. Bunsen and Dr. Playfair, Report on the Gases evolved from Iron Furnaces, with reference to the Theory of Smelting of Iron;—Dr. Richardson, Report on the Ichthyology of the Seas of China and Japan;—Report of the Committee on the Registration of Periodical Phenomena of Animals and Vegetables;—Fifth Report of the Committee on the Vitality of Seeds;—Appendix, &c.

Together with the Transactions of the Sections, Sir J. F. W. Herschel's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE SIXTEENTH MEETING, at Southampton, 1846, *Published at* 15*s.*

CONTENTS:—G. G. Stokes, Report on Recent Researches in Hydrodynamics;—Sixth Report of the Committee on the Vitality of Seeds;—Dr. Schunck, on the Colouring Matters of Madder;—J. Blake, on the Physiological Action of Medicines;—R. Hunt, Report on the Actinograph;—R. Hunt, Notices on the Influence of Light on the Growth of Plants;—R. L. Ellis, on the Recent Progress of Analysis;—Prof. Forchhammer, on Comparative Analytical Researches on Sea Water;—A. Erman, on the Calculation of the Gaussian Constants for 1829;—G. R. Porter, on the Progress, present Amount, and probable future Condition of the Iron Manufacture in Great Britain;—W. R. Birt, Third Report on Atmospheric Waves;—Prof. Owen, Report on the Archetype and Homologies of the Vertebrate Skeleton;—J. Phillips, on Anemometry;—Dr. J. Percy, Report on the Crystalline Flags;—Addenda to Mr. Birt's Report on Atmospheric Waves.

Together with the Transactions of the Sections, Sir R. I. Murchison's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE SEVENTEENTH MEETING, at Oxford, 1847, *Published at* 18*s.*

CONTENTS:—Prof. Langberg, on the Specific Gravity of Sulphuric Acid at different degrees of dilution, and on the relation which exists between the Development of Heat and the coincident contraction of Volume in Sulphuric Acid when mixed with Water;—R. Hunt, Researches on the Influence of the Solar Rays on the Growth of Plants;—R. Mallet, on the Facts of Earthquake Phenomena;—Prof. Nilsson, on the Primitive Inhabitants of Scandinavia;—W. Hopkins, Report on the Geological Theories of Elevation and Earthquakes;—Dr. W. B. Carpenter, Report on the Microscopic Structure of Shells;—Rev. W. Whewell and Sir James C. Ross, Report upon the Recommendation of an Expedition for the purpose of completing our Knowledge of the Tides;—Dr. Schunck, on Colouring Matters;—Seventh Report of the Committee on the Vitality of Seeds;—J. Glynn, on the Turbine or Horizontal Water-Wheel of France and Germany;—Dr. R. G. Latham, on the present state and

recent progress of Ethnographical Philology;—Dr. J. C. Prichard, on the various methods of Research which contribute to the Advancement of Ethnology, and of the relations of that Science to other branches of Knowledge;—Dr. C. C. J. Bunsen, on the results of the recent Egyptian researches in reference to Asiatic and African Ethnology, and the Classification of Languages;—Dr. C. Meyer, on the Importance of the Study of the Celtic Language as exhibited by the Modern Celtic Dialects still extant;—Dr. Max Müller, on the Relation of the Bengali to the Aryan and Aboriginal Languages of India;—W. R. Birt, Fourth Report on Atmospheric Waves;—Prof. W. H. Dove, Temperature Tables, with Introductory Remarks by Lieut.-Col. E. Sabine;—A. Erman and H. Petersen, Third Report on the Calculation of the Gaussian Constants for 1829.

Together with the Transactions of the Sections, Sir Robert Harry Inglis's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE EIGHTEENTH MEETING, at Swansea, 1848, *Published at* 9*s*.

CONTENTS:—Rev. Prof. Powell, A Catalogue of Observations of Luminous Meteors;—J. Glynn, on Water-pressure Engines;—R. A. Smith, on the Air and Water of Towns;—Eighth Report of Committee on the Growth and Vitality of Seeds;—W. R. Birt, Fifth Report on Atmospheric Waves;—E. Schunck, on Colouring Matters;—J. P. Budd, on the advantageous use made of the gaseous escape from the Blast Furnaces at the Ystalyfera Iron Works;—R. Hunt, Report of progress in the investigation of the Action of Carbonic Acid on the Growth of Plants allied to those of the Coal Formations;—Prof. H. W. Dove, Supplement to the Temperature Tables printed in the Report of the British Association for 1847;—Remarks by Prof. Dove on his recently constructed Maps of the Monthly Isothermal Lines of the Globe, and on some of the principal Conclusions in regard to Climatology deducible from them; with an introductory Notice by Lieut.-Col. E. Sabine;—Dr. Daubeny, on the progress of the investigation on the Influence of Carbonic Acid on the Growth of Ferns;—J. Phillips, Notice of further progress in Anemometrical Researches;—Mr. Mallet's Letter to the Assistant-General Secretary;—A. Erman, Second Report on the Gaussian Constants;—Report of a Committee relative to the expediency of recommending the continuance of the Toronto Magnetical and Meteorological Observatory until December 1850.

Together with the Transactions of the Sections, the Marquis of Northampton's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE NINETEENTH MEETING, at Birmingham, 1849, *Published at* 10*s*.

CONTENTS:—Rev. Prof. Powell, A Catalogue of Observations of Luminous Meteors;—Earl of Rosse, Notice of Nebulæ lately observed in the Six-feet Reflector;—Prof. Daubeny, on the Influence of Carbonic Acid Gas on the health of Plants, especially of those allied to the Fossil Remains found in the Coal Formation;—Dr. Andrews, Report on the Heat of Combination;—Report of the Committee on the Registration of the Periodic Phenomena of Plants and Animals;—Ninth Report of Committee on Experiments on the Growth and Vitality of Seeds;—F. Ronalds, Report concerning the Observatory of the British Association at Kew, from Aug. 9, 1848 to Sept. 12, 1849;—R. Mallet, Report on the Experimental Inquiry on Railway Bar Corrosion;—W. R. Birt, Report on the Discussion of the Electrical Observations at Kew.

Together with the Transactions of the Sections, the Rev. T. R. Robinson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTIETH MEETING, at Edinburgh, 1850, *Published at* 15*s*. (Out of Print.)

CONTENTS:—R. Mallet, First Report on the Facts of Earthquake Phenomena;—Rev. Prof. Powell, on Observations of Luminous Meteors;—Dr. T. Williams, on the Structure and History of the British Annelida;—T. C. Hunt, Results of Meteorological Observations taken at St. Michael's from the 1st of January, 1840, to the 31st

of December, 1849;—R. Hunt, on the present State of our Knowledge of the Chemical Action of the Solar Radiations;—Tenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Major-Gen. Briggs, Report on the Aboriginal Tribes of India;—F. Ronalds, Report concerning the Observatory of the British Association at Kew;—E. Forbes, Report on the Investigation of British Marine Zoology by means of the Dredge;—R. MacAndrew, Notes on the Distribution and Range in depth of Mollusca and other Marine Animals, observed on the coasts of Spain, Portugal, Barbary, Malta, and Southern Italy in 1849;—Prof. Allman, on the Present State of our Knowledge of the Freshwater Polyzoa;—Registration of the Periodical Phenomena of Plants and Animals;—Suggestions to Astronomers for the Observation of the Total Eclipse of the Sun on July 28, 1851.

Together with the Transactions of the Sections, Sir David Brewster's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FIRST MEETING, at Ipswich, 1851, *Published at* 16*s.* 6*d.*

CONTENTS:—Rev. Prof. Powell, on Observations of Luminous Meteors;—Eleventh Report of Committee on Experiments on the Growth and Vitality of Seeds;—Dr. J. Drew, on the Climate of Southampton;—Dr. R. A. Smith, on the Air and Water of Towns: Action of Porous Strata, Water, and Organic Matter;—Report of the Committee appointed to consider the probable Effects in an Economical and Physical Point of View of the Destruction of Tropical Forests;—A. Henfrey, on the Reproduction and supposed Existence of Sexual Organs in the Higher Cryptogamous Plants;—Dr. Daubeny, on the Nomenclature of Organic Compounds;—Rev. Dr. Donaldson, on two unsolved Problems in Indo-German Philology;—Dr. T. Williams, Report on the British Annelida;—R. Mallet, Second Report on the Facts of Earthquake Phenomena;—Letter from Prof. Henry to Col. Sabine, on the System of Meteorological Observations proposed to be established in the United States;—Col. Sabine, Report on the Kew Magnetographs;—J. Welsh, Report on the Performance of his three Magnetographs during the Experimental Trial at the Kew Observatory;—F. Ronalds, Report concerning the Observatory of the British Association at Kew, from September 12, 1850, to July 31, 1851;—Ordnance Survey of Scotland.

Together with the Transactions of the Sections, Prof. Airy's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SECOND MEETING, at Belfast, 1852, *Published at* 15*s.*

CONTENTS:—R. Mallet, Third Report on the Facts of Earthquake Phenomena;—Twelfth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1851–52;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants;—A Manual of Ethnological Inquiry;—Col. Sykes, Mean Temperature of the Day, and Monthly Fall of Rain at 127 Stations under the Bengal Presidency;—Prof. J. D. Forbes, on Experiments on the Laws of the Conduction of Heat;—R. Hunt, on the Chemical Action of the Solar Radiations;—Dr. Hodges, on the Composition and Economy of the Flax Plant;—W. Thompson, on the Freshwater Fishes of Ulster;—W. Thompson, Supplementary Report on the Fauna of Ireland;—W. Wills, on the Meteorology of Birmingham;—J. Thomson, on the Vortex-Water-Wheel;—J. B. Lawes and Dr. Gilbert, on the Composition of Foods in relation to Respiration and the Feeding of Animals.

Together with the Transactions of the Sections, Colonel Sabine's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-THIRD MEETING, at Hull, 1853, *Published at* 10*s.* 6*d.*

CONTENTS:—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1852–53;—James Oldham, on the Physical Features of the Humber;—James Oldham, on the Rise, Progress, and Present Position of Steam Navigation in Hull;—

William Fairbairn, Experimental Researches to determine the Strength of Locomotive Boilers, and the causes which lead to Explosion;—J. J. Sylvester, Provisional Report on the Theory of Determinants;—Professor Hodges, M.D., Report on the Gases evolved in Steeping Flax, and on the Composition and Economy of the Flax Plant;—Thirteenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Robert Hunt, on the Chemical Action of the Solar Radiations;—Dr. John P. Bell, Observations on the Character and Measurements of Degradation of the Yorkshire Coast;—First Report of Committee on the Physical Character of the Moon's Surface, as compared with that of the Earth;—R. Mallet, Provisional Report on Earthquake Wave-Transits; and on Seismometrical Instruments;—William Fairbairn, on the Mechanical Properties of Metals as derived from repeated Meltings, exhibiting the maximum point of strength and the causes of deterioration;—Robert Mallet, Third Report on the Facts of Earthquake Phenomena (continued).

Together with the Transactions of the Sections, Mr. Hopkins's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FOURTH MEETING, at Liverpool, 1854, *Published at* 18*s*.

CONTENTS:—R. Mallet, Third Report on the Facts of Earthquake Phenomena (continued);—Major-General Chesney, on the Construction and General Use of Efficient Life-Boats;—Rev. Prof. Powell, Third Report on the present State of our Knowledge of Radiant Heat;—Colonel Sabine, on some of the results obtained at the British Colonial Magnetic Observatories;—Colonel Portlock, Report of the Committee on Earthquakes, with their proceedings respecting Seismometers;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants, Part 2;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1853–54;—Second Report of the Committee on the Physical Character of the Moon's Surface;—W. G. Armstrong, on the Application of Water-Pressure Machinery;—J. B. Lawes and Dr. Gilbert, on the Equivalency of Starch and Sugar in Food;—Archibald Smith, on the Deviations of the Compass in Wooden and Iron Ships;—Fourteenth Report of Committee on Experiments on the Growth and Vitality of Seeds.

Together with the Transactions of the Sections, the Earl of Harrowby's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-FIFTH MEETING, at Glasgow, 1855, *Published at* 15*s*.

CONTENTS:—T. Dobson, Report on the Relation between Explosions in Coal-Mines and Revolving Storms;—Dr. Gladstone, on the Influence of the Solar Radiations on the Vital Powers of Plants growing under different Atmospheric Conditions, Part 3;—C. Spence Bate, on the British Edriophthalma;—J. F. Bateman, on the present state of our knowledge on the Supply of Water to Towns;—Fifteenth Report of Committee on Experiments on the Growth and Vitality of Seeds;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1854–55;—Report of Committee appointed to inquire into the best means of ascertaining those properties of Metals and effects of various modes of treating them which are of importance to the durability and efficiency of Artillery;—Rev. Prof. Henslow, Report on Typical Objects in Natural History;—A. Follett Osler, Account of the Self-registering Anemometer and Rain-Gauge at the Liverpool Observatory;—Provisional Reports.

Together with the Transactions of the Sections, the Duke of Argyll's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SIXTH MEETING, at Cheltenham, 1856, *Published at* 18*s*.

CONTENTS:—Report from the Committee appointed to investigate and report upon the effects produced upon the Channels of the Mersey by the alterations which within the last fifty years have been made in its Banks;—J. Thomson, Interim Report on progress in Researches on the Measurement of Water by Weir Boards;—

Dredging Report, Frith of Clyde, 1856;—Rev. B. Powell, Report on Observations of Luminous Meteors, 1855–1856;—Prof. Bunsen and Dr. H. E. Roscoe, Photochemical Researches;—Rev. James Booth, on the Trigonometry of the Parabola, and the Geometrical Origin of Logarithms;—R. MacAndrew, Report on the Marine Testaceous Mollusca of the North-east Atlantic and neighbouring Seas, and the physical conditions affecting their development;—P. P. Carpenter, Report on the present state of our knowledge with regard to the Mollusca of the West Coast of North America;—T. C. Eyton, Abstract of First Report on the Oyster Beds and Oysters of the British Shores;—Prof. Phillips, Report on Cleavage, and Foliation in Rocks, and on the Theoretical Explanations of these Phenomena, Part 1;—Dr. T. Wright, on the Stratigraphical Distribution of the Oolitic Echinodermata;—W. Fairbairn, on the Tensile Strength of Wrought Iron at various Temperatures;—C. Atherton, on Mercantile Steam Transport Economy;—J. S. Bowerbank, on the Vital Powers of the Spongiadæ;—Report of a Committee upon the Experiments conducted at Stormontfield, near Perth, for the artificial propagation of Salmon;—Provisional Report on the Measurement of Ships for Tonnage;—On Typical Forms of Minerals, Plants and Animals for Museums;—J. Thomson, Interim Report on Progress in Researches on the Measurement of Water by Weir Boards;—R. Mallet, on Observations with the Seismometer;—A. Cayley, on the Progress of Theoretical Dynamics;—Report of a Committee appointed to consider the formation of a Catalogue of Philosophical Memoirs.

Together with the Transactions of the Sections, Dr. Daubeny's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-SEVENTH MEETING, at Dublin, 1857, *Published at* 15s.

CONTENTS:—A. Cayley, Report on the recent progress of Theoretical Dynamics;—Sixteenth and Final Report of Committee on Experiments on the Growth and Vitality of Seeds;—James Oldham, C.E., continuation of Report on Steam Navigation at Hull;—Report of a Committee on the Defects of the present methods of Measuring and Registering the Tonnage of Shipping, as also of Marine Engine-Power, and to frame more perfect rules, in order that a correct and uniform principle may be adopted to estimate the Actual Carrying Capabilities and Working-power of Steam Ships;—Robert Were Fox, Report on the Temperature of some Deep Mines in Cornwall;—Dr. G. Plarr, de quelques Transformations de la Somme $\Sigma_0^{-\alpha} \frac{\alpha^{t|+1}\beta^{t|+1}\delta^{t|+1}}{1^{t|+1}\gamma^{t|+1}\epsilon^{t|+1}}$ a étant entier négatif, et de quelques cas dans lesquels cette somme est exprimable par une combinaison de factorielles, la notation $\alpha^{t|+1}$ désignant le produit des facteurs $\alpha\ (\alpha+1)\ (\alpha+2)$ &c.... $(\alpha+t-1)$;—G. Dickie, M.D., Report on the Marine Zoology of Strangford Lough, County Down, and corresponding part of the Irish Channel;—Charles Atherton, Suggestions for Statistical Inquiry into the Extent to which Mercantile Steam Transport Economy is affected by the Constructive Type of Shipping, as respects the Proportions of Length, Breadth, and Depth;—J. S. Bowerbank, Further Report on the Vitality of the Spongiadæ;—Dr. John P. Hodges, on Flax;—Major-General Sabine, Report of the Committee on the Magnetic Survey of Great Britain;—Rev. Baden Powell, Report on Observations of Luminous Meteors, 1856–57;—C. Vignoles, on the Adaptation of Suspension Bridges to sustain the passage of Railway Trains;—Prof. W. A. Miller, on Electro-Chemistry;—John Simpson, Results of Thermometrical Observations made at the *Plover's* Wintering-place, Point Barrow, latitude 71° 21′ N., long. 156° 17′ W., in 1852–54;—Charles James Hargreave, on the Algebraic Couple; and on the Equivalents of Indeterminate Expressions;—Thomas Grubb, Report on the Improvement of Telescope and Equatorial Mountings;—Prof. James Buckman, Report on the Experimental Plots in the Botanical Garden of the Royal Agricultural College at Cirencester;—William Fairbairn, on the Resistance of Tubes to Collapse;—George C. Hyndman, Report of the Proceedings of the Belfast Dredging Committee;—Peter W. Barlow, on the Mechanical Effect of combining Girders and Suspension Chains, and a Comparison of the Weight of Metal in Ordinary and Suspension Girders, to produce equal deflections with a given load;—J. Park Harrison, Evidences of Lunar Influence on Temperature;—Report on the Animal and Vegetable Products imported into Liver-

pool from the year 1851 to 1855 (inclusive);—Andrew Henderson, Report on the Statistics of Life-boats and Fishing-boats on the Coasts of the United Kingdom.

Together with the Transactions of the Sections, the Rev. H. Lloyd's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-EIGHTH MEETING, at Leeds, September 1858, *Published at* 20s.

CONTENTS:—R. Mallet, Fourth Report upon the Facts and Theory of Earthquake Phenomena;—Rev. Prof. Powell, Report on Observations of Luminous Meteors, 1857–1858;—R. H. Meade, on some Points in the Anatomy of the Araneidea or true Spiders, especially on the internal structure of their Spinning Organs;—W. Fairbairn, Report of the Committee on the Patent Laws;—S. Eddy, on the Lead Mining Districts of Yorkshire;—W. Fairbairn, on the Collapse of Glass Globes and Cylinders;—Dr. E. Perceval Wright and Prof. J. Reay Greene, Report on the Marine Fauna of the South and West Coasts of Ireland;—Prof. J. Thomson, on Experiments on the Measurement of Water by Triangular Notches in Weir Boards;—Major-General Sabine, Report of the Committee on the Magnetic Survey of Great Britain;—Michael Connel and William Keddie, Report on Animal, Vegetable, and Mineral Substances imported from Foreign Countries into the Clyde (including the Ports of Glasgow, Greenock, and Port Glasgow) in the years 1853, 1854, 1855, 1856, and 1857;—Report of the Committee on Shipping Statistics;—Rev. H. Lloyd, D.D., Notice of the Instruments employed in the Magnetic Survey of Ireland, with some of the Results;—Prof. J. R. Kinahan, Report of Dublin Dredging Committee, appointed 1857–58;—Prof. J. R. Kinahan, Report on Crustacea of Dublin District;—Andrew Henderson, on River Steamers, their Form, Construction, and Fittings, with reference to the necessity for improving the present means of Shallow-Water Navigation on the Rivers of British India;—George C. Hyndman, Report of the Belfast Dredging Committee;—Appendix to Mr. Vignoles' Paper 'On the Adaptation of Suspension Bridges to sustain the passage of Railway Trains;'—Report of the Joint Committee of the Royal Society and the British Association, for procuring a continuance of the Magnetic and Meteorological Observatories;—R. Beckley, Description of a Self-recording Anemometer.

Together with the Transactions of the Sections, Prof. Owen's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWENTY-NINTH MEETING, at Aberdeen, September 1859, *Published at* 15s.

CONTENTS:—George C. Foster, Preliminary Report on the Recent Progress and Present State of Organic Chemistry;—Professor Buckman, Report on the Growth of Plants in the Garden of the Royal Agricultural College, Cirencester;—Dr. A. Voelcker, Report on Field Experiments and Laboratory Researches on the Constituents of Manures essential to Cultivated Crops;—A. Thomson, of Banchory, Report on the Aberdeen Industrial Feeding Schools;—On the Upper Silurians of Lesmahagow, Lanarkshire;—Alphonse Gages, Report on the Results obtained by the Mechanico-Chemical Examination of Rocks and Minerals;—William Fairbairn, Experiments to determine the Efficiency of Continuous and Self-acting Brakes for Railway Trains;—Professor J. R. Kinahan, Report of Dublin Bay Dredging Committee for 1858–59;—Rev. Baden Powell, Report on Observations of Luminous Meteors for 1858–59;—Professor Owen, Report on a Series of Skulls of various Tribes of Mankind inhabiting Nepal, collected, and presented to the British Museum, by Bryan H. Hodgson, Esq., late Resident in Nepal, &c. &c.;—Messrs. Maskelyne, Hadow, Hardwich, and Llewelyn, Report on the Present State of our Knowledge regarding the Photographic Image;—G. C. Hyndman, Report of the Belfast Dredging Committee for 1859;—James Oldham, Continuation of Report of the Progress of Steam Navigation at Hull;—Charles Atherton, Mercantile Steam Transport Economy as affected by the Consumption of Coals;—Warren De La Rue, Report on the present state of Celestial Photography in England;—Professor Owen, on the Orders of Fossil and Recent Reptilia, and their Distribution in Time;—Balfour Stewart, on some Results of the Magnetic Survey of Scotland in the years 1857 and 1858, undertaken, at the request of the British Association, by the late John Welsh, Esq., F.R.S.;—W. Fairbairn, The

Patent Laws: Report of Committee on the Patent Laws;—J. Park Harrison, Lunar Influence on the Temperature of the Air:—Balfour Stewart, an Account of the Construction of the Self-recording Magnetographs at present in operation at the Kew Observatory of the British Association;—Professor H. J. Stephen Smith, Report on the Theory of Numbers, Part I.;—Report of the Committee on Steamship Performance;—Report of the Proceedings of the Balloon Committee of the British Association appointed at the Meeting at Leeds;—Prof. William K. Sullivan, Preliminary Report on the Solubility of Salts at Temperatures above 100° Cent., and on the Mutual Action of Salts in Solution.

Together with the Transactions of the Sections, Prince Albert's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTIETH MEETING, at Oxford, June and July 1860, *Published at* 15*s*.

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors, 1859–60;—J. R. Kinahan, Report of Dublin Bay Dredging Committee;—Rev. J. Anderson, Report on the Excavations in Dura Den;—Prof. Buckman, Report on the Experimental Plots in the Botanical Garden of the Royal Agricultural College, Cirencester;—Rev. R. Walker, Report of the Committee on Balloon Ascents;—Prof. W. Thomson, Report of Committee appointed to prepare a Self-recording Atmospheric Electrometer for Kew, and Portable Apparatus for observing Atmospheric Electricity;—William Fairbairn, Experiments to determine the Effect of Vibratory Action and long-continued Changes of Load upon Wrought-iron Girders;—R. P. Greg, Catalogue of Meteorites and Fireballs, from A.D. 2 to A.D. 1860;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part II.;—Vice-Admiral Moorsom, on the Performance of Steam-vessels, the Functions of the Screw, and the Relations of its Diameter and Pitch to the Form of the Vessel;—Rev. W. V. Harcourt, Report on the Effects of long-continued Heat, illustrative of Geological Phenomena;—Second Report of the Committee on Steamship Performance;—Interim Report on the Gauging of Water by Triangular Notches;—List of the British Marine Invertebrate Fauna.

Together with the Transactions of the Sections, Lord Wrottesley's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FIRST MEETING, at Manchester, September 1861, *Published at* £1.

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors;—Dr. E. Smith, Report on the Action of Prison Diet and Discipline on the Bodily Functions of Prisoners, Part I.;—Charles Atherton, on Freight as affected by Differences in the Dynamic Properties of Steamships;—Warren De La Rue, Report on the Progress of Celestial Photography since the Aberdeen Meeting;—B. Stewart, on the Theory of Exchanges, and its recent extension;—Drs. E. Schunck, R. Angus Smith, and H. E. Roscoe, on the Recent Progress and Present Condition of Manufacturing Chemistry in the South Lancashire District;—Dr. J. Hunt, on Ethno-Climatology; or, the Acclimatization of Man;—Prof. J. Thomson, on Experiments on the Gauging of Water by Triangular Notches;—Dr. A. Voelcker, Report on Field Experiments and Laboratory Researches on the Constituents of Manures essential to cultivated Crops;—Prof. H. Hennessy, Provisional Report on the Present State of our Knowledge respecting the Transmission of Sound-signals during Fogs at Sea;—Dr. P. L. Sclater and F. von Hochstetter, Report on the Present State of our Knowledge of the Birds of the Genus *Apteryx* living in New Zealand;—J. G. Jeffreys, Report of the Results of Deep-sea Dredging in Zetland, with a Notice of several Species of Mollusca new to Science or to the British Isles;—Prof. J. Phillips, Contributions to a Report on the Physical Aspect of the Moon;—W. R. Birt, Contribution to a Report on the Physical Aspect of the Moon;—Dr. Collingwood and Mr. Byerley, Preliminary Report of the Dredging Committee of the Mersey and Dee;—Third Report of the Committee on Steamship Performance;—J. G. Jeffreys, Preliminary Report on the Best Mode of preventing the Ravages of *Teredo* and other Animals in our Ships and Harbours;—R. Mallet, Report on the Experiments made at Holyhead to ascertain the Transit-Velocity of Waves, analogous to Earthquake Waves, through the local Rock Formations

—T. Dobson, on the Explosions in British Coal-Mines during the year 1859;—J. Oldham, Continuation of Report on Steam Navigation at Hull;—Prof. G. Dickie, Brief Summary of a Report on the Flora of the North of Ireland;—Prof. Owen, on the Psychical and Physical Characters of the Mincopies, or Natives of the Andaman Islands, and on the Relations thereby indicated to other Races of Mankind;—Colonel Sykes, Report of the Balloon Committee;—Major-General Sabine, Report on the Repetition of the Magnetic Survey of England;—Interim Report of the Committee for Dredging on the North and East Coasts of Scotland;—W. Fairbairn, on the Resistance of Iron Plates to Statical Pressure and the Force of Impact by Projectiles at High Velocities;—W. Fairbairn, Continuation of Report to determine the effect of Vibratory Action and long-continued Changes of Load upon Wrought-Iron Girders;—Report of the Committee on the Law of Patents;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part III.

Together with the Transactions of the Sections, Mr. Fairbairn's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SECOND MEETING at Cambridge, October 1862, *Published at £1.*

CONTENTS:—James Glaisher, Report on Observations of Luminous Meteors, 1861–62;—G. B. Airy, on the Strains in the Interior of Beams;—Archibald Smith and F. J. Evans, Report on the three Reports of the Liverpool Compass Committee;—Report on Tidal Observations on the Humber;—T. Aston, on Rifled Guns and Projectiles adapted for Attacking Armour-plate Defences;—Extracts, relating to the Observatory at Kew, from a Report presented to the Portuguese Government, by Dr. J. A. de Souza;—H. T. Mennell, Report on the Dredging of the Northumberland Coast and Dogger Bank;—Dr. Cuthbert Collingwood, Report upon the best means of advancing Science through the agency of the Mercantile Marine;—Messrs. Williamson, Wheatstone, Thomson, Miller, Matthiessen, and Jenkin, Provisional Report on Standards of Electrical Resistance;—Preliminary Report of the Committee for investigating the Chemical and Mineralogical Composition of the Granites of Donegal;—Prof. H. Hennessy, on the Vertical Movements of the Atmosphere considered in connection with Storms and Changes of Weather;—Report of Committee on the application of Gauss's General Theory of Terrestrial Magnetism to the Magnetic Variations;—Fleeming Jenkin, on Thermo-electric Currents in Circuits of one Metal;—W. Fairbairn, on the Mechanical Properties of Iron Projectiles at High Velocities;—A. Cayley, Report on the Progress of the Solution of certain Special Problems of Dynamics;—Prof. G. G. Stokes, Report on Double Refraction;—Fourth Report of the Committee on Steamship Performance;—G. J. Symons, on the Fall of Rain in the British Isles in 1860 and 1861;—J. Ball, on Thermometric Observations in the Alps;—J. G. Jeffreys, Report of the Committee for Dredging on the North and East Coasts of Scotland;—Report of the Committee on Technical and Scientific Evidence in Courts of Law;—James Glaisher, Account of Eight Balloon Ascents in 1862;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part IV.

Together with the Transactions of the Sections, the Rev. Prof. R. Willis's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-THIRD MEETING, at Newcastle-upon-Tyne, August and September 1863, *Published at £1 5s.*

CONTENTS:—Report of the Committee on the Application of Gun-cotton to Warlike Purposes;—A. Matthiessen, Report on the Chemical Nature of Alloys;—Report of the Committee on the Chemical and Mineralogical Constitution of the Granites of Donegal, and on the Rocks associated with them;—J. G. Jeffreys, Report of the Committee appointed for exploring the Coasts of Shetland by means of the Dredge;—G. D. Gibb, Report on the Physiological Effects of the Bromide of Ammonium;—C. K. Aken, on the Transmutation of Spectral Rays, Part I.;—Dr. Robinson, Report of the Committee on Fog Signals;—Report of the Committee on Standards of Electrical Resistance;—E. Smith, Abstract of Report by the Indian Government on the Foods

used by the Free and Jail Populations in India ;—A. Gages, Synthetical Researches on the Formation of Minerals, &c. ;—R. Mallet, Preliminary Report on the Experimental Determination of the Temperatures of Volcanic Foci, and of the Temperature, State of Saturation, and Velocity of the issuing Gases and Vapours ;—Report of the Committee on Observations of Luminous Meteors ;—Fifth Report of the Committee on Steamship Performance ;—G. J. Allman, Report on the Present State of our Knowledge of the Reproductive System in the Hydroida ;—J. Glaisher, Account of Five Balloon Ascents made in 1863 ;—P. P. Carpenter, Supplementary Report on the Present State of our Knowledge with regard to the Mollusca of the West Coast of North America ;—Prof. Airy, Report on Steam Boiler Explosions ;—C. W. Siemens, Observations on the Electrical Resistance and Electrification of some Insulating Materials under Pressures up to 300 Atmospheres ;—C. M. Palmer, on the Construction of Iron Ships and the Progress of Iron Shipbuilding on the Tyne, Wear, and Tees ;—Messrs. Richardson, Stevenson, and Clapham, on the Chemical Manufactures of the Northern Districts ;—Messrs. Sopwith and Richardson, on the Local Manufacture of Lead, Copper, Zinc, Antimony, &c. ;—Messrs. Daglish and Forster, on the Magnesian Limestone of Durham ;—I. L. Bell, on the Manufacture of Iron in connexion with the Northumberland and Durham Coal-field ;—T. Spencer, on the Manufacture of Steel in the Northern District ;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part V.

Together with the Transactions of the Sections, Sir William Armstrong's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FOURTH MEETING, at Bath, September 1864, *Published at* 18*s.*

CONTENTS :—Report of the Committee for Observations of Luminous Meteors ;—Report of the Committee on the best means of providing for a Uniformity of Weights and Measures ;—T. S. Cobbold, Report of Experiments respecting the Development and Migration of the Entozoa ;—B. W. Richardson, Report on the Physiological Action of Nitrite of Amyl ;—J. Oldham, Report of the Committee on Tidal Observations ;—G. S. Brady, Report on Deep-sea Dredging on the Coasts of Northumberland and Durham in 1864 ;—J. Glaisher, Account of Nine Balloon Ascents made in 1863 and 1864 ;—J. G. Jeffreys, Further Report on Shetland Dredgings ;—Report of the Committee on the Distribution of the Organic Remains of the North Staffordshire Coal-field ;—Report of the Committee on Standards of Electrical Resistance ;—G. J. Symons, on the Fall of Rain in the British Isles in 1862 and 1863 ;—W. Fairbairn, Preliminary Investigation of the Mechanical Properties of the proposed Atlantic Cable.

Together with the Transactions of the Sections, Sir Charles Lyell's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-FIFTH MEETING, at Birmingham, September 1865, *Published at* £1 5*s.*

CONTENTS :—J. G. Jeffreys, Report on Dredging among the Channel Isles ;—F. Buckland, Report on the Cultivation of Oysters by Natural and Artificial Methods ;—Report of the Committee for exploring Kent's Cavern ;—Report of the Committee on Zoological Nomenclature ;—Report on the Distribution of the Organic Remains of the North Staffordshire Coal-field ;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall ;—Interim Report on the Resistance of Water to Floating and Immersed Bodies ;—Report on Observations of Luminous Meteors ;—Report on Dredging on the Coast of Aberdeenshire ;—J. Glaisher, Account of Three Balloon Ascents ;—Interim Report on the Transmission of Sound under Water ;—G. J. Symons, on the Rainfall of the British Isles ;—W. Fairbairn, on the Strength of Materials considered in relation to the Construction of Iron Ships ;—Report of the Gun-Cotton Committee ;—A. F. Osler, on the Horary and Diurnal Variations in the Direction and Motion of the Air at Wrottesley, Liverpool, and Birmingham ;—B. W. Richardson, Second Report on the Physiological Action of certain of the Amyl Compounds ;—Report on further Researches in the Lingula-

flags of South Wales;—Report of the Lunar Committee for Mapping the Surface of the Moon;—Report on Standards of Electrical Resistance;—Report of the Committee appointed to communicate with the Russian Government respecting Magnetical Observations at Tiflis;—Appendix to Report on the Distribution of the Vertebrate Remains from the North Staffordshire Coal-field;—H. Woodward, First Report on the Structure and Classification of the Fossil Crustacea;—Prof. H. J. S. Smith, Report on the Theory of Numbers, Part VI.;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the interests of Science:—A. G. Findlay, on the Bed of the Ocean;—Prof. A. W. Williamson, on the Composition of Gases evolved by the Bath Spring called King's Bath.

Together with the Transactions of the Sections, Prof. Phillips's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SIXTH MEETING, at Nottingham, August 1866, *Published at* £1 4*s*.

CONTENTS:—Second Report on Kent's Cavern, Devonshire;—A. Matthiessen, Preliminary Report on the Chemical Nature of Cast Iron;—Report on Observations of Luminous Meteors;—W. S. Mitchell, Report on the Alum Bay Leaf-bed;—Report on the Resistance of Water to Floating and Immersed Bodies;—Dr. Norris, Report on Muscular Irritability;—Dr. Richardson, Report on the Physiological Action of certain compounds of Amyl and Ethyl;—H. Woodward, Second Report on the Structure and Classification of the Fossil Crustacea;—Second Report on the 'Menevian Group,' and the other Formations at St. David's, Pembrokeshire;—J. G. Jeffreys, Report on Dredging among the Hebrides;—Rev. A. M. Norman, Report on the Coasts of the Hebrides, Part II.;—J. Alder, Notices of some Invertebrata, in connexion with Mr. Jeffreys's Report;—G. S. Brady, Report on the *Ostracoda* dredged amongst the Hebrides;—Report on Dredging in the Moray Firth;—Report on the Transmission of Sound-Signals under Water;—Report of the Lunar Committee;—Report of the Rainfall Committee;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the Interests of Science;—J. Glaisher, Account of Three Balloon Ascents;—Report on the Extinct Birds of the Mascarene Islands;—Report on the Penetration of Ironclad Ships by Steel Shot;—J. A. Wanklyn, Report on Isomerism among the Alcohols;—Report on Scientific Evidence in Courts of Law;—A. L. Adams, Second Report on Maltese Fossiliferous Caves, &c.

Together with the Transactions of the Sections, Mr. Grove's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-SEVENTH MEETING, at Dundee, September 1867, *Published at* £1 6*s*.

CONTENTS:—Report of the Committee for Mapping the Surface of the Moon;—Third Report on Kent's Cavern, Devonshire;—On the present State of the Manufacture of Iron in Great Britain;—Third Report on the Structure and Classification of the Fossil Crustacea;—Report on the Physiological Action of the Methyl Compounds;—Preliminary Report on the Exploration of the Plant-Beds of North Greenland;—Report of the Steamship Performance Committee;—On the Meteorology of Port Louis, in the Island of Mauritius;—On the Construction and Works of the Highland Railway;—Experimental Researches on the Mechanical Properties of Steel;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall;—Supplement to a Report on the Extinct Didine Birds of the Mascarene Islands;—Report on Observations of Luminous Meteors;—Fourth Report on Dredging among the Shetland Isles;—Preliminary Report on the Crustacea, &c., procured by the Shetland Dredging Committee in 1867;—Report on the Foraminifera obtained in the Shetland Seas;—Second Report of the Rainfall Committee;—Report on the best means of providing for a Uniformity of Weights and Measures, with reference to the interests of Science;—Report on Standards of Electrical Resistance.

Together with the Transactions of the Sections, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-EIGHTH MEETING, at Norwich, August 1868, *Published at* £1 5*s.*

CONTENTS:—Report of the Lunar Committee —Fourth Report on Kent's Cavern, Devonshire;—On Puddling Iron;—Fourth Report on the Structure and Classification of the Fossil Crustacea;—Report on British Fossil Corals;—Report on Spectroscopic Investigations of Animal Substances;—Report of Steamship Performance Committee;—Spectrum Analysis of the Heavenly Bodies;—On Stellar Spectrometry;—Report on the Physiological Action of the Methyl and allied Compounds;—Report on the Action of Mercury on the Biliary Secretion;—Last Report on Dredging among the Shetland Isles;—Reports on the Crustacea, &c., and on the Annelida and Foraminifera from the Shetland Dredgings;—Report on the Chemical Nature of Cast Iron, Part I.;—Interim Report on the Safety of Merchant Ships and their Passengers;—Report on Observations of Luminous Meteors;—Preliminary Report on Mineral Veins containing Organic Remains;—Report on the Desirability of Explorations between India and China;—Report of Rainfall Committee;—Report on Synthetical Researches on Organic Acids;—Report on Uniformity of Weights and Measures;—Report of the Committee on Tidal Observations;—Report of the Committee on Underground Temperature;—Changes of the Moon's Surface;—Report on Polyatomic Cyanides.

Together with the Transactions of the Sections, Dr. Hooker's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE THIRTY-NINTH MEETING, at Exeter, August 1869, *Published at* £1 2*s.*

CONTENTS:—Report on the Plant-beds of North Greenland;—Report on the existing knowledge on the Stability, Propulsion, and Seagoing qualities of Ships; —Report on Steam-boiler Explosions;—Preliminary Report on the Determination of the Gases existing in Solution in Well-waters;—The Pressure of Taxation on Real Property;—On the Chemical Reactions of Light discovered by Prof. Tyndall;—On Fossils obtained at Kiltorkan Quarry, co. Kilkenny;—Report of the Lunar Committee;—Report on the Chemical Nature of Cast Iron;—Report on the Marine Fauna and Flora of the South Coast of Devon and Cornwall;—Report on the Practicability of establishing a 'Close Time' for the Protection of Indigenous Animals;—Experimental Researches on the Mechanical Properties of Steel;—Second Report on British Fossil Corals;—Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals for Photographing;—Report on the Rate of Increase of Underground Temperature;—Fifth Report on Kent's Cavern, Devonshire;—Report on the Connexion between Chemical Constitution and Physiological Action;—On Emission, Absorption, and Reflection of Obscure Heat;—Report on Observations of Luminous Meteors;—Report on Uniformity of Weights and Measures; —Report on the Treatment and Utilization of Sewage;—Supplement to Second Report of the Steamship-Performance Committee;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on Mineral Veins in Carboniferous Limestone and their Organic Contents;—Notes on the Foraminifera of Mineral Veins and the Adjacent Strata;—Report of the Rainfall Committee;—Interim Report on the Laws of the Flow and Action of Water containing Solid Matter in Suspension;—Interim Report on Agricultural Machinery;—Report on the Physiological Action of Methyl and Allied Series;—On the Influence of Form considered in Relation to the Strength of Railway-axles and other portions of Machinery subjected to Rapid Alterations of Strain;—On the Penetration of Armour-plates with Long Shells of Large Capacity fired obliquely;—Report on Standards of Electrical Resistance.

Together with the Transactions of the Sections, Prof. Stokes's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTIETH MEETING, at Liverpool, September 1870, *Published at* 18*s.*

CONTENTS:—Report on Steam-boiler Explosions;—Report of the Committee on the Hæmatite Iron-ores of Great Britain and Ireland;—Report on the Sedimentary Deposits of the River Onny;—Report on the Chemical Nature of Cast Iron;—Report on the practicability of establishing a 'Close Time' for the protection of Indigenous Animals;—Report on Standards of Electrical Resistance;—Sixth Report on Kent's Cavern;—Third Report on Underground Temperature;—Second Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals;—Second Report on the Stability, Propulsion, and Seagoing Qualities of Ships;—Report on Earthquakes in Scotland;—Report on the Treatment and Utilization of Sewage;—Report on Observations of Luminous Meteors, 1869-70;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on Tidal Observations;—On a new Steam-power Meter;—Report on the Action of the Methyl and Allied Series;—Report of the Rainfall Committee;—Report on the Heat generated in the Blood in the Process of Arterialization;—Report on the best means of providing for Uniformity of Weights and Measures.

Together with the Transactions of the Sections, Prof. Huxley's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-FIRST MEETING, at Edinburgh, August 1871, *Published at* 16*s.*

CONTENTS:—Seventh Report on Kent's Cavern;—Fourth Report on Underground Temperature;—Report on Observations of Luminous Meteors, 1870–71;—Fifth Report on the Structure and Classification of the Fossil Crustacea;—Report of the Committee appointed for the purpose of urging on Her Majesty's Government the expediency of arranging and tabulating the results of the approaching Census in the three several parts of the United Kingdom in such a manner as to admit of ready and effective comparison;—Report of the Committee appointed for the purpose of Superintending the Publication of Abstracts of Chemical Papers;—Report of the Committee for discussing Observations of Lunar Objects suspected of change;—Second Provisional Report on the Thermal Conductivity of Metals;—Report on the Rainfall of the British Isles;—Third Report on the British Fossil Corals;—Report on the Heat generated in the Blood during the Process of Arterialization;—Report of the Committee appointed to consider the subject of Physiological Experimentation;—Report on the Physiological Action of Organic Chemical Compounds;—Report of the Committee appointed to get cut and prepared Sections of Mountain-Limestone Corals;—Second Report on Steam-Boiler Explosions;—Report on the Treatment and Utilization of Sewage;—Report on promoting the Foundation of Zoological Stations in different parts of the World;—Preliminary Report on the Thermal Equivalents of the Oxides of Chlorine;—Report on the practicability of establishing a 'Close Time' for the protection of Indigenous Animals;—Report on Earthquakes in Scotland;—Report on the best means of providing for a Uniformity of Weights and Measures;—Report on Tidal Observations.

Together with the Transactions of the Sections, Sir William Thomson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SECOND MEETING, at Brighton, August 1872, *Published at* £1 4*s.*

CONTENTS:—Report on the Gaussian Constants for the Year 1829;—Second Supplementary Report on the Extinct Birds of the Mascarene Islands;—Report of the Committee for Superintending the Monthly Reports of the Progress of Chemistry;—Report of the Committee on the best means of providing for a Uniformity of Weights and Measures;—Eighth Report on Kent's Cavern;—Report on promoting the Foundation of Zoological Stations in different parts of the World;—Fourth Report

on the Fauna of South Devon;—Preliminary Report of the Committee appointed to Construct and Print Catalogues of Spectral Rays arranged upon a Scale of Wave-numbers;—Third Report on Steam-Boiler Explosions;—Report on Observations of Luminous Meteors, 1871–72;—Experiments on the Surface-friction experienced by a Plane moving through Water;—Report of the Committee on the Antagonism between the Action of Active Substances;—Fifth Report on Underground Temperature;—Preliminary Report of the Committee on Siemens's Electrical-Resistance Pyrometer:—Fourth Report on the Treatment and Utilization of Sewage;—Interim Report of the Committee on Instruments for Measuring the Speed of Ships and Currents;—Report on the Rainfall of the British Isles;—Report of the Committee on a Geographical Exploration of the Country of Moab;—Sur l'élimination des Fonctions Arbitraires;—Report on the Discovery of Fossils in certain remote parts of the North-western Highlands;—Report of the Committee on Earthquakes in Scotland;—Fourth Report on Carboniferous-Limestone Corals;—Report of the Committee to consider the mode in which new Inventions and Claims for Reward in respect of adopted Inventions are examined and dealt with by the different Departments of Government;—Report of the Committee for discussing Observations of Lunar Objects suspected of change;—Report on the Mollusca of Europe;—Report of the Committee for investigating the Chemical Constitution and Optical Properties of Essential Oils;—Report on the practicability of establishing a 'Close Time' for the preservation of Indigenous Animals;—Sixth Report on the Structure and Classification of Fossil Crustacea;—Report of the Committee appointed to organize an Expedition for observing the Solar Eclipse of Dec. 12, 1871;—Preliminary Report of a Committee on Terato-embryological Inquiries;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on Tidal Observations;—On the Brighton Waterworks;—On Amsler's Planimeter.

Together with the Transactions of the Sections, Dr. Carpenter's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-THIRD MEETING, at Bradford, September 1873, *Published at £1 5s.*

CONTENTS:—Report of the Committee on Mathematical Tables;—Observations on the Application of Machinery to the Cutting of Coal in Mines;—Concluding Report on the Maltese Fossil Elephants;—Report of the Committee for ascertaining the Existence in different parts of the United Kingdom of any Erratic Blocks or Boulders;—Fourth Report on Earthquakes in Scotland;—Ninth Report on Kent's Cavern;—On the Flint and Chert Implements found in Kent's Cavern;—Report of the Committee for Investigating the Chemical Constitution and Optical Properties of Essential Oils;—Report of Inquiry into the Method of making Gold-assays; —Fifth Report on the Selection and Nomenclature of Dynamical and Electrical Units;—Report of the Committee on the Labyrinthodonts of the Coal-measures;—Report of the Committee appointed to construct and print Catalogues of Spectral Rays;—Report of the Committee appointed to explore the Settle Caves;—Sixth Report on Underground Temperature;—Report on the Rainfall of the British Isles;—Seventh Report on Researches in Fossil Crustacea;—Report on Recent Progress in Elliptic and Hyperelliptic Functions;—Report on the desirability of establishing a 'Close Time' for the preservation of Indigenous Animals;—Report on Luminous Meteors; —On the Visibility of the Dark Side of Venus;—Report of the Committee for the Foundation of Zoological Stations in different parts of the World;—Second Report of the Committee for collecting Fossils from North-western Scotland;—Fifth Report on the Treatment and Utilization of Sewage;—Report of the Committee on Monthly Reports of the Progress of Chemistry;—On the Bradford Waterworks;—Report on the possibility of Improving the Methods of Instruction in Elementary Geometry; —Interim Report of the Committee on Instruments for Measuring the Speed of Ships, &c.;—Report of the Committee for Determinating High Temperatures by means of the Refrangibility of Light evolved by Fluid or Solid Substances;—On a periodicity of Cyclones and Rainfall in connexion with Sun-spot Periodicity;—Fifth Report on the Structure of Carboniferous-Limestone Corals;—Report of the Committee on preparing and publishing brief forms of Instructions for Travellers, Ethnologists, &c.;—Preliminary Note from the Committee on the Influence of Forests

on the Rainfall;—Report of the Sub-Wealden Exploration Committee;—Report of the Committee on Machinery for obtaining a Record of the Roughness of the Sea and Measurement of Waves near shore;—Report on Science Lectures and Organization;—Second Report on Science Lectures and Organization.

Together with the Transactions of the Sections, Prof. A. W. Williamson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS of the FORTY-FOURTH MEETING, at Belfast, August 1874, *Published at £1 5s.*

Contents:—Tenth Report on Kent's Cavern;—Report for investigating the Chemical Constitution and Optical Properties of Essential Oils;—Second Report of the Sub-Wealden Exploration Committee;—On the Recent Progress and Present State of Systematic Botany;—Report of the Committee for investigating the Nature of Intestinal Secretion;—Report of the Committee on the Teaching of Physics in Schools;—Preliminary Report for investigating Isomeric Cresols and their Derivatives;—Third Report of the Committee for collecting Fossils from localities in North-western Scotland;—Report on the Rainfall of the British Isles;—On the Belfast Harbour;—Report of Inquiry into the Method of making Gold-assays;—Report of a Committee on Experiments to determine the Thermal Conductivities of certain Rocks;—Second Report on the Exploration of the Settle Caves;—On the Industrial uses of the Upper Bann River;—Report of the Committee on the Structure and Classification of the Labyrinthodonts;—Second Report of the Committee for recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England and Wales, &c.;—Sixth Report on the Treatment and Utilization of Sewage;—Report on the Anthropological Notes and Queries for the use of Travellers;—On Cyclone and Rainfall Periodicities;—Fifth Report on Earthquakes in Scotland;—Report of the Committee appointed to prepare and print Tables of Wave-numbers;—Report of the Committee for testing the new Pyrometer of Mr. Siemens;—Report to the Lords Commissioners of the Admiralty on Experiments for the Determination of the Frictional Resistance of Water on a Surface &c.;—Second Report for the Selection and Nomenclature of Dynamical and Electrical Units;—On Instruments for measuring the Speed of Ships;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee to inquire into the economic effects of Combinations of Labourers and Capitalists;—Preliminary Report on Dredging on the Coasts of Durham and North Yorkshire;—Report on Luminous Meteors;—Report on the best means of providing for a Uniformity of Weights and Measures.

Together with the Transactions of the Sections, Prof. John Tyndall's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS of the FORTY-FIFTH MEETING, at Bristol, August 1875, *Published at £1 5s.*

Contents:—Eleventh Report on Kent's Cavern;—Seventh Report on Underground Temperature;—Report on the Zoological Station at Naples;—Report of a Committee appointed to inquire into the Methods employed in the Estimation of Potash and Phosphoric Acid in Commercial Products;—Report on the present state of our Knowledge of the Crustacea;—Second Report on the Thermal Conductivities of certain Rocks;—Preliminary Report of the Committee for extending the Observations on the Specific Volumes of Liquids;—Sixth Report on Earthquakes in Scotland;—Seventh Report on the Treatment and Utilization of Sewage;—Report of the Committee for furthering the Palestine Explorations;—Third Report of the Committee for recording the position, height above the sea, lithological characters, size, and origin of the Erratic Blocks of England and Wales, &c.;—Report of the Rainfall Committee;—Report of the Committee for investigating Isomeric Cresols and their Derivatives;—Report of the Committee for investigating the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—On the Steering of Screw-Steamers;—Second Report of

the Committee on Combinations of Capital and Labour;—Report on the Method of making Gold-assays;—Eighth Report on Underground Temperature;—Tides in the River Mersey;—Sixth Report of the Committee on the Structure of Carboniferous Corals;—Report of the Committee appointed to explore the Settle Caves;—On the River Avon (Bristol), its Drainage-Area, &c.;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee appointed to superintend the Publication of the Monthly Reports of the Progress of Chemistry;—Report on Dredging off the Coasts of Durham and North Yorkshire in 1874;—Report on Luminous Meteors;—On the Analytical Forms called Trees;—Report of the Committee on Mathematical Tables;—Report of the Committee on Mathematical Notation and Printing;—Second Report of the Committee for investigating Intestinal Secretion;—Third Report of the Sub-Wealden Exploration Committee.

Together with the Transactions of the Sections, Sir John Hawkshaw's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SIXTH MEETING, at Glasgow, September 1876, *Published at* £1 5*s*.

CONTENTS:—Twelfth Report on Kent's Cavern;—Report on Improving the Methods of Instruction in Elementary Geometry;—Results of a Comparison of the British-Association Units of Electrical Resistance;—Third Report on the Thermal Conductivities of certain Rocks;—Report of the Committee on the practicability of adopting a Common Measure of Value in the Assessment of Direct Taxation;—Report of the Committee for testing experimentally Ohm's Law;—Report of the Committee on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report of the Committee on the Effect of Propellers on the Steering of Vessels;—On the Investigation of the Steering Qualities of Ships;—Seventh Report on Earthquakes in Scotland;—Report on the present state of our Knowledge of the Crustacea;—Second Report of the Committee for investigating the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—Fourth Report of the Committee on the Erratic Blocks of England and Wales, &c.;—Fourth Report of the Committee on the Exploration of the Settle Caves (Victoria Cave);—Report on Observations of Luminous Meteors, 1875–76;—Report on the Rainfall of the British Isles, 1875–76;—Ninth Report on Underground Temperature;—Nitrous Oxide in the Gaseous and Liquid States;—Eighth Report on the Treatment and Utilization of Sewage;—Improved Investigations on the Flow of Water through Orifices, with Objections to the modes of treatment commonly adopted;—Report of the Anthropometric Committee;—On Cyclone and Rainfall Periodicities in connexion with the Sun-spot Periodicity;—Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee on Tidal Observations;—Third Report of the Committee on the Conditions of Intestinal Secretion and Movement;—Report of the Committee for collecting and suggesting subjects for Chemical Research.

Together with the Transactions of the Sections, Dr. T. Andrews's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-SEVENTH MEETING, at Plymouth, August 1877, *Published at* £1 4*s*.

CONTENTS:—Thirteenth Report on Kent's Cavern;—Second and Third Reports on the Methods employed in the estimation of Potash and Phosphoric Acid in Commercial Products;—Report on the present state of our Knowledge of the Crustacea (Part III.);—Third Report on the Circulation of the Underground Waters in the New Red Sandstone and Permian Formations of England;—Fifth Report on the Erratic Blocks of England, Wales, and Ireland;—Fourth Report on the Thermal Conductivities of certain Rocks;—Report on Observations of Luminous Meteors, 1876–77;—Tenth Report on Underground Temperature;—Report on the Effect of Propellers on the Steering of Vessels;—Report on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on some Double Compounds of

Nickel and Cobalt;—Fifth Report on the Exploration of the Settle Caves (Victoria Cave);—Report on the Datum Level of the Ordnance Survey of Great Britain;—Report on the Zoological Station at Naples;—Report of the Anthropometric Committee;—Report on the Conditions under which Liquid Carbonic Acid exists in Rocks and Minerals.

Together with the Transactions of the Sections, Prof. Allen Thomson's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-EIGHTH MEETING, at Dublin, August 1878, *Published at* £1 4*s*.

CONTENTS:—Catalogue of the Oscillation-Frequencies of Solar Rays;—Report on Mr. Babbage's Analytical Machine;—Third Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee for arranging for the taking of certain Observations in India, and Observations on Atmospheric Electricity at Madeira;—Report on the commencement of Secular Experiments upon the Elasticity of Wires;—Report on the Chemistry of some of the lesser-known Alkaloids, especially Veratria and Bebeerine;—Report on the best means for the Development of Light from Coal-Gas;—Fourteenth Report on Kent's Cavern;—Report on the Fossils in the North-west Highlands of Scotland;—Fifth Report on the Thermal Conductivities of certain Rocks;—Report on the possibility of establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on the occupation of a Table at the Zoological Station at Naples;—Report of the Anthropometric Committee;—Report on Patent Legislation;—Report on the Use of Steel for Structural Purposes;—Report on the Geographical Distribution of the Chiroptera;—Recent Improvements in the Port of Dublin;—Report on Mathematical Tables;—Eleventh Report on Underground Temperature;—Report on the Exploration of the Fermanagh Caves;—Sixth Report on the Erratic Blocks of England, Wales, and Ireland;—Report on the present state of our Knowledge of the Crustacea (Part IV.);—Report on two Caves in the neighbourhood of Tenby;—Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—Second Report on the Datum-level of the Ordnance Survey of Great Britain;—Report on instruments for measuring the Speed of Ships;—Report of Investigations into a Common Measure of Value in Direct Taxation;—Report on Sunspots and Rainfall;—Report on Observations of Luminous Meteors;—Sixth Report on the Exploration of the Settle Caves (Victoria Cave);—Report on the Kentish Boring Exploration;—Fourth Report on the Circulation of Underground Waters in the Jurassic, New Red Sandstone, and Permian Formations, with an Appendix on the Filtration of Water through Triassic Sandstone;—Report on the Effect of Propellers on the Steering of Vessels.

Together with the Transactions of the Sections, Mr. Spottiswoode's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FORTY-NINTH MEETING, at Sheffield, August 1879, *Published at* £1 4*s*.

CONTENTS:—Report on the commencement of Secular Experiments upon the Elasticity of Wires;—Fourth Report of the Committee for determining the Mechanical Equivalent of Heat;—Report of the Committee for endeavouring to procure reports on the Progress of the Chief Branches of Mathematics and Physics;—Twelfth Report on Underground Temperature;—Report on Mathematical Tables;—Sixth Report on the Thermal Conductivities of certain Rocks;—Report on Observations of Atmospheric Electricity at Madeira;—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on the Calculation of Sun-Heat Coefficients;—Second Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—Report on Observations of Luminous Meteors;—Report on the question of Improvements in Astronomical Clocks;—Report of the Committee for improving an Instrument for detecting the presence of Fire-damp in Mines;—Report on the Chemistry of some of the lesser-known Alkaloids, especially Veratria

and Beeberine;—Seventh Report on the Erratic Blocks of England, Wales, and Ireland;—Fifteenth Report on Kent's Cavern;—Report on certain Caves in Borneo;—Fifth Report on the Circulation of Underground Waters in the Jurassic, Red Sandstone, and Permian Formations of England;—Report on the Tertiary (Miocene) Flora, &c., of the Basalt of the North of Ireland;—Report on the possibility of Establishing a 'Close Time' for the Protection of Indigenous Animals;—Report on the Marine Zoology of Devon and Cornwall;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on Excavations at Portstewart and elsewhere in the North of Ireland;—Report of the Anthropometric Committee;—Report on the Investigation of the Natural History of Socotra;—Report on Instruments for measuring the Speed of Ships;—Third Report on the Datum-level of the Ordnance Survey of Great Britain;—Second Report on Patent Legislation;—On Self-acting Intermittent Siphons and the conditions which determine the commencement of their Action;—On some further Evidence as to the Range of the Palæozoic Rocks beneath the South-east of England;—Hydrography, Past and Present.

Together with the Transactions of the Sections, Prof. Allman's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTIETH MEETING, at Swansea, August and September 1880, *Published at £1 4s.*

CONTENTS:—Report on the Measurement of the Lunar Disturbance of Gravity;—Thirteenth Report on Underground Temperature;—Report of the Committee for devising and constructing an improved form of High Insulation Key for Electrometer Work;—Report on Mathematical Tables;—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on Observations of Luminous Meteors;—Report on the question of Improvements in Astronomical Clocks;—Report on the commencement of Secular Experiments on the Elasticity of Wires;—Sixteenth and concluding Report on Kent's Cavern;—Report on the mode of reproduction of certain species of Ichthyosaurus from the Lias of England and Würtemburg;—Report on the Carboniferous Polyzoa;—Report on the 'Geological Record';—Sixth Report on the Circulation of the Underground Waters in the Permian, New Red Sandstone, and Jurassic Formations of England, and the Quantity and Character of the Water supplied to towns and districts from these formations;—Second Report on the Tertiary (Miocene) Flora, &c., of the Basalt of the North of Ireland;—Eighth Report on the Erratic Blocks of England, Wales, and Ireland;—Report on an Investigation for the purpose of fixing a Standard of White Light;—Report of the Anthropometric Committee;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Second Report on the Marine Zoology of South Devon;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on accessions to our knowledge of the Chiroptera during the past two years (1878–80);—Preliminary Report on the accurate measurement of the specific inductive capacity of a good Sprengel Vacuum, and the specific resistance of gases at different pressures;—Comparison of Curves of the Declination Magnetographs at Kew, Stonyhurst, Coimbra, Lisbon, Vienna, and St. Petersburg;—First Report on the Caves of the South of Ireland;—Report on the Investigation of the Natural History of Socotra;—Report on the German and other systems of teaching the Deaf to speak;—Report of the Committee for considering whether it is important that H.M. Inspectors of Elementary Schools should be appointed with reference to their ability for examining in the scientific specific subjects of the Code in addition to other matters;—On the Anthracite Coal and Coalfield of South Wales;—Report on the present state of our knowledge of Crustacea (Part V.);—Report on the best means for the Development of Light from Coal-gas of different qualities (Part II.);—Report on Palæontological and Zoological Researches in Mexico;—Report on the possibility of establishing a 'Close Time' for Indigenous Animals;—Report on the present state of our knowledge of Spectrum Analysis;—Report on Patent Legislation;—Preliminary Report on the present Appropriation of Wages, &c.;—Report on the present state of knowledge of the application of Quadratures and Interpolation to Actual Data;—The French Deep-sea Exploration in the Bay of Biscay;—Third Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—List of

Works on the Geology, Mineralogy, and Palæontology of Wales (to the end of 1873);—On the recent Revival in Trade.

Together with the Transactions of the Sections, Dr. A. C. Ramsay's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTY-FIRST MEETING, at York, August and September 1881, *Published at £1 4s.*

CONTENTS:—Report on the Calculation of Tables of the Fundamental Invariants of Algebraic Forms;—Report on Recent Progress in Hydrodynamics (Part I.);—Report on Meteoric Dust;—Second Report on the Calculation of Sun-heat Coefficients;—Fourteenth Report on Underground Temperature;—Report on the Measurement of the Lunar Disturbance of Gravity;—Second Report on an Investigation for the purpose of fixing a Standard of White Light;—Final Report on the Thermal Conductivities of certain Rocks;—Report on the manner in which Rudimentary Science should be taught, and how Examinations should be held therein, in Elementary Schools;—Third Report on the Tertiary Flora of the North of Ireland;—Report on the Method of Determining the Specific Refraction of Solids from their Solutions;—Fourth Report on the Stationary Tides in the English Channel and in the North Sea, &c.;—Second Report on Fossil Polyzoa;—Report on the Maintenance of the Scottish Zoological Station;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on the Migration of Birds;—Report on the Natural History of Socotra;—Report on the Natural History of Timor-laut;—Report on the Marine Fauna of the Southern Coast of Devon and Cornwall;—Report on the Earthquake Phenomena of Japan;—Ninth Report on the Erratic Blocks of England, Wales, and Ireland;—Second Report on the Caves of the South of Ireland;—Report on Patent Legislation;—Report of the Anthropometric Committee;—Report on the Appropriation of Wages, &c.;—Report on Observations of Luminous Meteors;—Report on Mathematical Tables;—Seventh Report on the Circulation of Underground Waters in the Jurassic, New Red Sandstone, and Permian Formations of England, and the Quality and Quantity of the Water supplied to Towns and Districts from these Formations;—Report on the present state of our Knowledge of Spectrum Analysis;—Interim Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—On some new Theorems on Curves of Double Curvature;—Observations of Atmospheric Electricity at the Kew Observatory during 1880;—On the Arrestation of Infusorial Life by Solar Light;—On the Effects of Oceanic Currents upon Climates;—On Magnetic Disturbances and Earth Currents;—On some Applications of Electric Energy to Horticultural and Agricultural purposes;—On the Pressure of Wind upon a Fixed Plane Surface;—On the Island of Socotra;—On some of the Developments of Mechanical Engineering during the last Half-Century.

Together with the Transactions of the Sections, Sir John Lubbock's Address, and Recommendations of the Association and its Committees.

REPORT OF THE FIFTY-SECOND MEETING, at Southampton, August 1882, *Published at £1 4s.*

CONTENTS:—Report on the Calculation of Tables of Fundamental Invariants of Binary Quantics;—Report (provisional) of the Committee for co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year 1861;—Report of the Committee appointed for fixing a Standard of White Light;—Report on Recent Progress in Hydrodynamics (Part II.);—Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—Fifteenth Report on Underground Temperature, with Summary of the Results contained in the Fifteen Reports of the Underground Temperature Committee;—Report on Meteoric Dust;—Second Report on the Measurement of the Lunar Disturbance of Gravity;—Report on the present state of our Knowledge of Spectrum Analysis;—Report on the Investigation by means of Photography of the Ultra-Violet Spark Spectra emitted by Metallic Elements, and their combinations under varying conditions;—Report of the Committee for preparing a new Series of Tables of Wave-lengths of the Spectra of the Elements;—Report on the Methods employed in the Calibration of Mercurial Ther-

mometers;—Second Report on the Earthquake Phenomena of Japan;—Eighth Report on the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Water supplied to various Towns and Districts from these Formations;—Report on the Conditions under which ordinary Sedimentary Materials may be converted into Metamorphic Rocks;—Report on Explorations in Caves of Carboniferous Limestone in the South of Ireland;—Report on the Preparation of an International Geological Map of Europe;—Tenth Report on the Erratic Blocks of England, Wales, and Ireland;—Report on Fossil Polyzoa (Jurassic Species—British Area only);—Preliminary Report on the Flora of the 'Halifax Hard Bed,' Lower Coal Measures;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Report of the Committee appointed for obtaining Photographs of the Typical Races in the British Isles;—Preliminary Report on the Ancient Earthwork in Epping Forest known as the Loughton Camp;—Second Report on the Natural History of Timor-laut;—Report of the Committee for carrying out the recommendations of the Anthropometric Committee of 1880, especially as regards the anthropometry of children and of females, and the more complete discussion of the collected facts;—Report on the Natural History of Socotra and the adjacent Highlands of Arabia and Somali Land;—Report on the Maintenance of the Scottish Zoological Station;—Report on the Migration of Birds;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on the Survey of Eastern Palestine;—Final Report on the Appropriation of Wages, &c.;—Report on the workings of the revised New Code, and of other legislation affecting the teaching of Science in Elementary Schools;—Report on Patent Legislation;—Report of the Committee for determining a Gauge for the manufacture of various small Screws;—Report on the best means of ascertaining the Effective Wind Pressure to which buildings and structures are exposed;—On the Boiling Points and Vapour Tension of Mercury, of Sulphur, and of some Compounds of Carbon, determined by means of the Hydrogen Thermometer;—On the Method of Harmonic Analysis used in deducing the Numerical Values of the Tides of long period, and on a Misprint in the Tidal Report for 1872;—List of Works on the Geology and Palæontology of Oxfordshire, of Berkshire, and of Buckinghamshire;—Notes on the oldest Records of the Sea-Route to China from Western Asia;—The Deserts of Africa and Asia;—State of Crime in England, Scotland, and Ireland in 1880;—On the Treatment of Steel for the Construction of Ordnance, and other purposes;—The Channel Tunnel;—The Forth Bridge.

Together with the Transactions of the Sections, Dr. C. W. Siemens's Address, and Recommendations of the Association and its Committees.

REPORT OF THE FIFTY-THIRD MEETING, at Southport, September 1883, *Published at £1 4s.*

CONTENTS:—Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—Sixteenth Report on Underground Temperature;—Report on the best Experimental Methods that can be used in observing Total Solar Eclipses;—Report on the Harmonic Analysis of Tidal Observations;—Report of the Committee for co-operating with the Meteorological Society of the Mauritius in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year 1861;—Report on Mathematical Tables;—Report of the Committee for co-operating with the Scottish Meteorological Society in making Meteorological Observations on Ben Nevis;—Report on Meteoric Dust;—Report of the Committee appointed for fixing a Standard of White Light;—Report on Chemical Nomenclature;—Report on the investigation by means of Photography of the Ultra-Violet Spark Spectra emitted by Metallic Elements, and their combinations under varying conditions;—Report on Isomeric Naphthalene Derivatives;—Report on Explorations in Caves in the Carboniferous Limestone in the South of Ireland;—Report on the Exploration of Raygill Fissure, Yorkshire;—Eleventh Report on the Erratic Blocks of England, Wales, and Ireland;—Ninth Report on the Circulation of the Underground Waters in the Permeable Formations of England, and the Quality and Quantity of the Water supplied to various Towns and Districts from these Formations;—Report on the Fossil Plants of Halifax;—Fourth Report on Fossil Polyzoa;—Fourth Report on the Tertiary Flora of the North of Ireland;—Report on the Earthquake Phenomena of Japan;—Report on the Fossil Phyllopoda of the

Palæozoic Rocks;—Third Report on the Natural History of Timor Laut;—Report on the Natural History of Socotra and the adjacent Highlands of Arabia and Somali Land;—Report on the Exploration of Kilima-njaro and the adjoining mountains of Eastern Equatorial Africa;—Report on the Migration of Birds;—Report on the Maintenance of the Scottish Zoological Station;—Report on the Occupation of a Table at the Zoological Station at Naples;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Report on the Ancient Earthwork in Epping Forest, known as the 'Loughton' or 'Cowper's' Camp;—Final Report of the Anthropometric Committee;—Report of the Committee for defining the Facial Characteristics of the Races and Principal Crosses in the British Isles, and obtaining Illustrative Photographs;—Report on the Survey of Eastern Palestine;—Report on the workings of the proposed revised New Code, and of other legislation affecting the teaching of Science in Elementary Schools;—Report on Patent Legislation;—Report of the Committee for determining a Gauge for the manufacture of various small Screws;—Report of the 'Local Scientific Societies' Committee;—On some results of photographing the Solar Corona without an Eclipse;—On Lamé's Differential Equation;—Recent Changes in the Distribution of Wealth in relation to the Incomes of the Labouring Classes;—On the Mersey Tunnel;—On Manganese Bronze;—Nest Gearing.

Together with the Transactions of the Sections, Professor Cayley's Address, and Recommendations of the Association and its Committees.

REPORT OF THE FIFTY-FOURTH MEETING, at Montreal, August and September, 1884, *Published at 1l. 4s.*

CONTENTS:—Report of the Committee for considering and advising on the best means for facilitating the adoption of the Metric System of Weights and Measures in Great Britain;—Report of the Committee for considering the best methods of recording the direct intensity of Solar Radiation;—Report of the Committee for constructing and issuing practical Standards for use in Electrical Measurements;—Report of the Committee for co-operating with the Meteorological Society of the Mauritius, in their proposed publication of Daily Synoptic Charts of the Indian Ocean from the year 1861;—Second Report on the Harmonic Analysis of Tidal Observations;—Report of the Committee for co-operating with Mr. E. J. Lowe in his project of establishing a Meteorological Observatory near Chepstow on a permanent and scientific basis;—Report of the Committee for co-operating with the Directors of the Ben Nevis Observatory in making Meteorological Observations on Ben Nevis;—Report of the Committee for reducing and tabulating the Tidal Observations in the English Channel, made with the Dover Tide-gauge, and for connecting them with Observations made on the French Coast;—Fourth Report on Meteoric Dust;—Second Report on Chemical Nomenclature;—Report on Isomeric Naphthalene Derivatives;—Second Report on the Fossil Phyllopoda of the Palæozoic Rocks;—Tenth Report on the Circulation of Underground Waters in the Permeable Formations of England and Wales, and the Quantity and Character of the Water supplied to various Towns and Districts from these Formations;—Fifth and last Report on Fossil Polyzoa;—Twelfth Report on the Erratic Blocks of England, Wales, and Ireland;—Report upon the National Geological Surveys of Europe;—Report on the Rate of Erosion of the Sea-coasts of England and Wales, and the Influence of the Artificial Abstraction of Shingle or other material in that action;—Report on the Exploration of the Raygill Fissure in Lothersdale, Yorkshire;—Fourth Report on the Earthquake Phenomena of Japan;—Report on the occupation of a Table at the Zoological Station at Naples;—Fourth Report on the Natural History of Timor Laut;—Report on the Influence of Bodily Exercise on the Elimination of Nitrogen;—Report on the Migration of Birds;—Report on the Preparation of a Bibliography of certain groups of Invertebrata;—Report on the Exploration of Kilima-njaro, and the adjoining mountains of Eastern Equatorial Africa;—Report on the Survey of Eastern Palestine;—Report of the Committee for defraying the expenses of completing the Preparation of the final Report of the Anthropometric Committee;—Report on the teaching of Science in Elementary Schools;—Report of the Committee for determining a Gauge for the manufacture of the various small Screws used in Telegraphic and Electrical Apparatus, in Clockwork, and for other analogous purposes;—Report on Patent Legislation;—Report of the Committee for defining the Facial Charac-

teristics of the Races and Principal Crosses in the British Isles, and obtaining Illustrative Photographs with a view to their publication;—Report on the present state of our knowledge of Spectrum Analysis;—Report of the Committee for preparing a new series of Wave-length Tables of the Spectra of the Elements;—On the Connection between Sun-spots and Terrestrial Phenomena;—On the Seat of the Electromotive Forces in the Voltaic Cell;—On the Archæan Rocks of Great Britain;—On the Concordance of the Mollusca inhabiting both sides of the North Atlantic and the intermediate Seas;—On the Characteristics of the North American Flora; On the Theory of the Steam Engine;—Improvements in Coast Signals, with Supplementary Remarks on the New Eddystone Lighthouse;—On American Permanent Way.

Together with the Transactions of the Sections, Lord Rayleigh's Address, and Recommendations of the Association and its Committees.

BRITISH ASSOCIATION

FOR

THE ADVANCEMENT OF SCIENCE.

LIST

OF

OFFICERS, COUNCIL, AND MEMBERS,

CORRECTED TO APRIL 6, 1886.

[*Office of the Association:—22 Albemarle Street, London, W.*]

OFFICERS AND COUNCIL, 1885-86.

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Professor W. H. FLOWER, LL.D., F.R.S., F.L.S., F.G.S., Pres. Z.S., Director of the Natural History Museum, London.
Professor JOHN STRUTHERS, M.D., LL.D.

PRESIDENT ELECT.

Sir WILLIAM DAWSON, C.M.G., M.A., LL.D., F.R.S., F.G.S., Principal of McGill College, Montreal, Canada.

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The Right Hon. LORD NORTON, K.C.M.G.
The Right Hon. LORD WROTTESLEY, Lord-Lieutenant of Staffordshire.
The Right Rev. the LORD BISHOP OF WORCESTER, D.D.
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Rev. A. R. VARDY, M.A.
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LOCAL SECRETARIES FOR THE MEETING AT BIRMINGHAM.

Rev. H. W. CROSSKEY, LL.D., F.G.S. | J. BARHAM CARSLAKE, Esq. | CHARLES J. HART, Esq.

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J. D. GOODMAN, Esq.

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FLOWER, Professor W. H., F.R.S.
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MOSELEY, Professor H. N., F.R.S.
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A. G. VERNON HARCOURT, Esq., M.A., LL.D., F.R.S., F.C.S., Cowley Grange, Oxford.

SECRETARY.

ARTHUR T. ATCHISON, Esq., M.A., 22 Albemarle Street, London, W.

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Professor A. W. WILLIAMSON, Ph.D., LL.D., F.R.S., F.C.S., University College, London, W.C.

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Prof. Tyndall, D.C.L., F.R.S.
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Sir A. C. Ramsay, LL.D., F.R.S.
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Dr. Michael Foster, Sec. R.S.
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LIST OF MEMBERS

OF THE

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

1885.

* indicates Life Members entitled to the Annual Report.
§ indicates Annual Subscribers entitled to the Annual Report.
‡ indicates Subscribers not entitled to the Annual Report.
Names without any mark before them are Life Members not entitled to the Annual Report.
Names of Members of the GENERAL COMMITTEE are printed in SMALL CAPITALS.
Names of Members whose addresses are incomplete or not known are in *italics*.

Notice of changes of residence should be sent to the Secretary, 22 Albemarle Street, London, W.

Year of Election.

Abbatt, Richard, F.R.A.S. Marlborough House, Burgess Hill, Sussex.
1881. *Abbott, R. T. G. Woodbine House, Trinity-road, Scarborough.
1863. *ABEL, Sir FREDERICK AUGUSTUS, C.B., D.C.L., F.R.S., F.C.S., Director of the Chemical Establishment of the War Department. Royal Arsenal, Woolwich.
1856. ‡Abercrombie, John, M.D. 39 Welbeck-street, London, W.
1885. *ABERDEEN, The Right Hon. the Earl of, LL.D. 37 Grosvenor-square, London, W.
1885. §Aberdeen, The Countess of. 37 Grosvenor-square, London, W.
1885. §Abernethy, David W. Ferryhill Cottage, Aberdeen.
1863. *ABERNETHY, JAMES, M.Inst.C.E., F.R.S.E. 4 Delahay-street, Westminster, S.W.
1885. §Abernethy, James W. 2 Rubislaw-place, Aberdeen.
1873. *ABNEY, Captain W. DE W., R.E., F.R.S., F.R.A.S., F.C.S. Willeslie House, Wetherby-road, South Kensington, London, S.W.
1877. §Ace, Rev. Daniel, D.D., F.R.A.S. Laughton, near Gainsborough, Lincolnshire.
1884. ‡Achison, George. Collegiate Institute, Toronto, Canada.
1873. ‡Ackroyd, Samuel. Greaves-street, Little Horton, Bradford, Yorkshire.

Year of Election.

1882. *Acland, Alfred Dyke. Oxford.
1869. ‡Acland, Charles T. D., M.P. Sprydoncote, Exeter.
1877. *Acland, Francis E. Dyke, R.A. School of Gunnery, Shoeburyness.
1873. *Acland, Rev. H. D., M.A. Nymet St. George, South Molton, Devon.
1873. *ACLAND, Sir HENRY W. D., K.C.B., M.A., M.D., LL.D., F.R.S., F.R.G.S., Radcliffe Librarian and Regius Professor of Medicine in the University of Oxford. Broad-street, Oxford.
1877. *Acland, Theodore Dyke, M.A. 79 Lambeth Palace-road, London, S.E.
1860. ‡ACLAND, Sir THOMAS DYKE, Bart., M.A., D.C.L., M.P. Sprydoncote, Exeter; and Athenæum Club, London, S.W.
1884. ‡Adams, Frank Donovan. Geological Survey, Ottawa, Canada.
1876. ‡Adams, James. 9 Royal-crescent West, Glasgow.
*ADAMS, JOHN COUCH, M.A., LL.D., F.R.S., F.R.A.S., Director of the Observatory and Lowndean Professor of Astronomy and Geometry in the University of Cambridge. The Observatory, Cambridge.
1871. §Adams, John R. 3 Queen's-gate-terrace, London, S.W.
1879. *ADAMS, Rev. THOMAS, M.A. Underhill, Low Fell, Gateshead.
1877. ‡ADAMS, WILLIAM. 3 Sussex-terrace, Plymouth.
1869. *ADAMS, WILLIAM GRYLLS, M.A., F.R.S., F.G.S., F.C.P.S., Professor of Natural Philosophy and Astronomy in King's College, London. 43 Notting Hill-square, London, W.
1873. ‡Adams-Acton, John. Margutta House, 103 Marylebone-road, London, N.W.
1879. ‡Adamson, Robert, M.A., LL.D., Professor of Logic and Political Economy in Owens College, Manchester. 60 Parsonage-road, Withington, Manchester.
1860. *Adie, Patrick. Broadway, Westminster, S.W.
1865. *Adkins, Henry. Northfield, near Birmingham.
1883. §Adshead, Samuel. School of Science, Macclesfield.
1884. ‡Agnew, Cornelius R. 266 Maddison-avenue, New York, U.S.A.
1884. ‡Aikins, Dr. W. T. Jarvis-street, Toronto, Canada.
1864. *Ainsworth, David. The Flosh, Cleator, Carnforth.
1871. *Ainsworth, John Stirling. Harecroft, Cumberland.
Ainsworth, Peter. Smithills Hall, Bolton.
1871. ‡Ainsworth, William M. The Flosh, Cleator, Carnforth.
AIRY, Sir GEORGE BIDDELL, K.C.B., M.A., LL.D., D.C.L., F.R.S., F.R.A.S. The White House, Croom's Hill, Greenwich, S.E.
1871. §Aitken, John, F.R.S.E. Darroch, Falkirk, N.B.
Akroyd, Edward. Bankfield, Halifax.
1884. *Alabaster, H. 22 Paternoster-row, London, E.C.
1862. ‡ALCOCK, Sir RUTHERFORD, K.C.B., D.C.L., F.R.G.S. The Athenæum Club, Pall Mall, London, S.W.
1861. *Alcock, Thomas, M.D. Oakfield, Sale, Manchester.
*Aldam, William. Frickley Hall, near Doncaster.
1883. ‡Alexander, George. Kildare-street Club, Dublin.
1873. ‡Alexander, Reginald, M.D. 13 Hallfield-road, Bradford, Yorkshire.
1858. ‡ALEXANDER, WILLIAM, M.D. Halifax.
1850. ‡Alexander, Rev. William Lindsay, D.D., F.R.S.E. Pinkieburn, Musselburgh, by Edinburgh.
1883. §Alger, Miss Ethel. Widey Court, near Plymouth.
1883. §Alger, W. H. Widey Court, near Plymouth.
1883. §Alger, Mrs. W. H. Widey Court, near Plymouth.
1867. ‡Alison, George L. C. Dundee.
1859. ‡Allan, Alexander. Scottish Central Railway, Perth.
1885. §Allan, David. West Cults, near Aberdeen.

Year of Election.

1871. ‡Allan, G., M.Inst.C.E. 101 Leadenhall-street, London, E.C.
1871. ‡ALLEN, ALFRED H., F.C.S. 1 Surrey-street, Sheffield.
1879. *Allen, Rev. A. J. C. The College, Chester.
1884. §Allen, Rev. George. Shaw Vicarage, Oldham.
1878. ‡Allen, John Romilly. 5 Albert-terrace, Regent's Park, London, N.W.
1861. ‡Allen, Richard. Didsbury, near Manchester.
1863. ‡Allhusen, C. Elswick Hall, Newcastle-on-Tyne.
*ALLMAN, GEORGE J., M.D., LL.D., F.R.S. L. & E., M.R.I.A., F.L.S., Emeritus Professor of Natural History in the University of Edinburgh. Ardmore, Parkstone, Dorset.
1873. ‡Ambler, John. North Park-road, Bradford, Yorkshire.
1883. §Amery, John Sparke. Druid House, Ashburton, Devon.
1883. §Amery, Peter Fabyan Sparke. Druid House, Ashburton, Devon.
1884. ‡Ami, Henry. Geological Survey, Ottawa, Canada.
1876. ‡Anderson, Alexander. 1 St. James's-place, Hillhead, Glasgow.
1878. ‡Anderson, Beresford. Saint Ville, Killiney.
1885. §Anderson, Charles Clinton. 47 Penywern-road, London, S.W.
1850. ‡Anderson, Charles William. Cleadon, South Shields.
1883. ‡Anderson, Miss Constance. 17 Stonegate, York.
1885. *Anderson, Hugh Kerr. Frognal Park, Hampstead, London, N.W.
1850. ‡*Anderson, John. 31 St. Bernard's-crescent, Edinburgh.*
1874. ‡Anderson, John, J.P., F.G.S. Holywood, Belfast.
1876. ‡Anderson, Matthew. 137 St. Vincent-street, Glasgow.
1859. ‡ANDERSON, PATRICK. 15 King-street, Dundee.
1880. *ANDERSON, TEMPEST, M.D., B.Sc. 17 Stonegate, York.
1886. *Anderson, William, M.Inst.C.E. Lesney House, Erith, Kent.
1880. §Andrew, Mrs. 126 Jamaica-street, Stepney, London, E
1883. ‡Andrew, Thomas, F.G.S. 18 Southernhay, Exeter.
1880. *Andrews, Thornton, M.Inst.C.E. Cefn Eithen, Swansea.
1883. §Anelay, Miss M. Mabel. Girton College, Cambridge.
1877. §ANGELL, JOHN, F.C.S. The Grammar School, Manchester.
1878. ‡Anson, Frederick H. 9 Delahay-street, Westminster, S.W.
Anthony, John, M.D. 6 Greenfield-crescent, Edgbaston, Birmingham.
APJOHN, JAMES, M.D., F.R.S., F.C.S., M.R.I.A., Professor of Chemistry in Trinity College, Dublin. 32 Baggot-street, Dublin.
1868. ‡Appleby, C. J. Emerson-street, Bankside, Southwark, London, S.E.
1884. ‡Archbold, George. Oswego, New York, U.S.A.
1870. ‡Archer, Francis, jun. 3 Brunswick-street, Liverpool.
1874. ‡Archer, William, F.R.S., M.R.I.A. 11 South Frederick-street, Dublin.
1884. *Archibald, E. Douglas. Grosvenor House, Tunbridge Wells.
1851. ‡ARGYLL, His Grace the Duke of, K.G., K.T., D.C.L., F.R.S. L. & E., F.G.S. Argyll Lodge, Kensington, London, W.; and Inverary, Argyleshire.
1884. §Arlidge, John Thomas, M.D., B.A. The High Grove, Stoke-upon-Trent.
1883. §Armistead, Richard. Wharncliffe House, Beaufort-road, Brooklands, near Manchester.
1883. *Armistead, William. Wharncliffe House, Beaufort-road, Brooklands, near Manchester.
1861. ‡Armitage, William. 95 Portland-street, Manchester.
1867. *Armitstead, George. Errol Park, Errol, N.B.
1879. *Armstrong, Sir Alexander, K.C.B., M.D., LL.D., F.R.S., F.R.G.S. The Albany, London, W.

Year of Election.

1873. §ARMSTRONG, HENRY E., Ph.D., F.R.S., Sec.C.S., Professor of Chemistry in the City and Guilds of London Institute Central Institution, Exhibition-road, London, S.W. 55 Granville Park, Lewisham, S.E.
1876. ‡Armstrong, James. Bay Ridge, Long Island, New York, U.S.A.
1884. ‡Armstrong, Robert B. Junior Carlton Club, Pall Mall, London, S.W.
Armstrong, Thomas. Higher Broughton, Manchester.
1857. *ARMSTRONG, Sir WILLIAM GEORGE, C.B., LL.D., D.C.L., F.R.S. Jesmond Dene, Newcastle-upon-Tyne.
1870. ‡Arnott, Thomas Reid. Bramshill, Harlesden Green, London, N.W.
1853. *Arthur, Rev. William, M.A. Clapham Common, London, S.W.
1870. *Ash, Dr. T. Linnington. Holsworthy, North Devon.
1874. ‡Ashe, Isaac, M.B. Dundrum, Co. Dublin.
1884. *Asher, Asher, M.D. 18 Endsleigh-street, Tavistock-square, London, W.C.
1873. ‡Ashton, John. Gorse Bank House, Windsor-road, Oldham.
Ashton, Thomas. Ford Bank, Didsbury, Manchester.
1866. ‡Ashwell, Henry. Mount-street, New Basford, Nottingham.
*Ashworth, Edmund. Egerton Hall, Bolton-le-Moors.
Ashworth, Henry. Turton, near Bolton.
1861. ‡Aspland, Alfred. Dukinfield, Ashton-under-Lyne.
1875. *Aspland, W. Gaskell. Care of Manager, Union Bank, Chancery-lane, London, W.C.
1861. §Asquith, J. R. Infirmary-street, Leeds.
1861. ‡Aston, Theodore. 11 New-square, Lincoln's Inn, London, W.C.
1872. *ATCHISON, ARTHUR T., M.A. (SECRETARY.) 22 Albemarle-street, London, W.
1858. ‡Atherton, Charles. Sandover, Isle of Wight.
1861. ‡Atkin, Eli. Newton Heath, Manchester.
1865. *ATKINSON, EDMUND, Ph.D., F.C.S. Portesbery Hill, Camberley, Surrey.
1884. ‡Atkinson, Edward. Brookline, Massachusetts, Boston, U.S.A.
1863. *Atkinson, G. Clayton. 21 Windsor-terrace, Newcastle-on-Tyne.
1861. ‡Atkinson, Rev. J. A. Longsight Rectory, near Manchester.
1858. *Atkinson, John Hastings. 12 East Parade, Leeds.
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1881. ‡Atkinson, J. T. The Quay, Selby, Yorkshire.
1883. *Atkinson, Miss Maria. The Laurels, Sale, Cheshire.
1881. ‡Atkinson, Robert William. Town Hall-buildings, Newcastle-on-Tyne.
Atkinson, William. Claremont, Southport.
1863. *ATTFIELD, Professor J., M.A., Ph.D., F.R.S., F.C.S. 17 Bloomsbury-square, London, W.C.
1884. ‡Auchincloss, W. S. 209 Church-street, Philadelphia, U.S.A.
1860. *Austin-Gourlay, Rev. William E. C., M.A. The Rectory, Stanton St. John, near Oxford.
1865. *Avery, Thomas. Church-road, Edgbaston, Birmingham.
1881. ‡AXON, W. E. A. Fern Bank, Higher Broughton, Manchester.
1877. *AYRTON, W. E., F.R.S., Professor of Applied Physics in the City and Guilds of London Institute Central Institution, Exhibition-road, London, S.W.

*BABINGTON, CHARLES CARDALE, M.A., F.R.S., F.L.S., F.G.S., Professor of Botany in the University of Cambridge. 5 Brookside, Cambridge.

Year of Election.

1884. ‡Baby, Hon. G. Montreal, Canada.
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1863. ‡Backhouse, T. W. West Hendon House, Sunderland.
1883. *Backhouse, W. A. St. John's Wolsingham, near Darlington.
1881. ‡Baden-Powell, George S., C.M.G., M.A., M.P., F.R.A.S., F.S.S. 8 St. George's-place, Hyde Park, London, S.W.
1877. ‡Badock, W. F. Badminton House, Clifton Park, Bristol.
1883. ‡Bagrual, P. H. St. Stephen's Club, Westminster, S.W.
1883. ‡Baildon, Dr. 65 Manchester-road, Southport.
1883. §Bailey, Charles, F.L.S. Ashfield, College-road, Whalley Range, Manchester.
1870. §Bailey, Dr. Francis J. 51 Grove-street, Liverpool.
1878. ‡Bailey, John. 3 Blackhall-place, Dublin.
1865. ‡Bailey, Samuel, F.G.S. The Peck, Walsall.
1855. ‡Bailey, William. Horseley Fields Chemical Works, Wolverhampton.
1866. ‡Baillon, Andrew. St. Mary's Gate, Nottingham.
1866. ‡Baillon, L. St. Mary's Gate, Nottingham.
1878. ‡Baily, Walter. 176 Haverstock-hill, London, N.W.
1857. ‡Baily, William Hellier, F.L.S., F.G.S., Acting Palæontologist to the Geological Survey of Ireland. 14 Hume-street, Dublin.
1885. §Bain, Alexander, M.A., LL.D., Rector of the University of Aberdeen. Ferryhill Lodge, Aberdeen.
1873. ‡Bain, Sir James. 3 Park-terrace, Glasgow.
1885. §Bain, William N. 7 Aytoun-road, Pollockshiels, Glasgow.
*Bainbridge, Robert Walton. Middleton House, Middleton-in-Teesdale, by Darlington.
*Baines, Sir Edward, J.P. Belgrave-mansions, Grosvenor-gardens, London, S.W.; and St. Ann's Hill, Burley, Leeds.
1858. ‡*Baines Frederick. Burley, near Leeds.*
1858. ‡Baines, T. Blackburn. 'Mercury' Office, Leeds.
1882. *Baker, Benjamin, M.Inst.C.E. 2 Queen Square-place, Westminster, S.W.
1866. ‡Baker, Francis B. Sherwood-street, Nottingham.
1861. *Baker, John. The Gables, Buxton.
1881. ‡Baker, Robert, M.D. The Retreat, York.
1865. ‡Baker, Robert L. Barham House, Leamington.
1863. ‡Baker, William. 6 Taptonville, Sheffield.
1875. *Baker, W. Mills. The Holmes, Stoke Bishop, Bristol.
1875. ‡Baker, W. Proctor. Brislington, Bristol.
1881. ‡Baldwin, Rev. G. W. de Courcy, M.A. Lord Mayor's Walk, York.
1884. ‡Balete, Professor E. Polytechnic School, Montreal, Canada.
1871. ‡Balfour, G. W. Whittinghame, Prestonkirk, Scotland.
1875. ‡Balfour, Isaac Bayley, D.Sc., M.D., F.R.S. L. & E., Professor of Botany in the University of Oxford. Botanic Gardens, Oxford.
1878. *Ball, Charles Bent, M.D. 16 Lower Fitzwilliam-street, Dublin.
1835. *Ball, John, M.A., F.R.S., F.L.S., M.R.I.A. 10 Southwell-gardens, South Kensington, London, S.W.
1866. *Ball, Sir Robert Stawell, M.A., LL.D., F.R.S., F.R.A.S., Andrews Professor of Astronomy in the University of Dublin, and Astronomer Royal for Ireland. The Observatory, Dunsink, Co. Dublin.
1878. ‡Ball, Valentine, M.A., F.R.S., F.G.S., Director of the Museum of Science and Art, Dublin.
1883. *Ball, W. W. Rouse, M.A. Trinity College, Cambridge.
1883. ‡*Balloch, Miss. Glasgow.*

Year of
Election.

1884. ‡Ballon, Dr. Naham. Sandwich, Illinois, U.S.A.
1869. ‡Bamber, Henry K., F.C.S. 5 Westminster-chambers, Victoria-street, Westminster, S.W.
1882. ‡Bance, Major Edward. Limewood, The Avenue, Southampton.
1852. ‡Bangor, Viscount. Castleward, Co. Down, Ireland.
1879. ‡Banham, H. French. Mount View, Glossop-road, Sheffield.
1870. ‡BANISTER, Rev. WILLIAM, B.A. St. James's Mount, Liverpool.
1884. ‡Bannatyne, Hon. A. G. Winnipeg, Canada.
1883. §Banning, John J. 28 Westcliffe-road, Southport.
1884. ‡Barbeau, E. J. Montreal, Canada.
1866. ‡Barber, John. Long-row, Nottingham.
1884. §Barber, Rev. S. F. Great Snoring Vicarage, Fakenham, Norfolk.
1861. *Barbour, George. Bankhead, Broxton, Chester.
1859. ‡Barbour, George F. 11 George-square, Edinburgh.
1855. ‡Barclay, Andrew. Kilmarnock, Scotland.
Barclay, Charles, F.S.A. Bury Hill, Dorking.
1871. ‡Barclay, George. 17 Coates-crescent, Edinburgh.
1852. *Barclay, J. Gurney. 54 Lombard-street, London, E.C.
1860. *Barclay, Robert. High Leigh, Hoddesden, Herts.
1876. *Barclay, Robert. 21 Park-terrace, Glasgow.
1868. *Barclay, W. L. 54 Lombard-street, London, E.C.
1881. §Barfoot, William, J.P. Whelford-place, Leicester.
1882. ‡Barford, J. G. Above Bar, Southampton.
1863. *Barford, James Gale, F.C.S. Wellington College, Wokingham, Berkshire.
1860. *Barker, Rev. Arthur Alcock, B.D. East Bridgford Rectory, Nottingham.
1879. ‡Barker, Elliott. 2 High-street, Sheffield.
1882. *Barker, Miss J. M. Hexham House, Hexham.
1879. *Barker, Rev. Philip C., M.A., LL.B. Rotherham, Yorkshire.
1865. ‡Barker, Stephen. 30 Frederick-street, Edgbaston, Birmingham.
1870. ‡BARKLY, Sir HENRY, G.C.M.G., K.C.B., F.R.S., F.R.G.S. 1 Bina-gardens, South Kensington, London, S.W.
1873. ‡Barlow, Crawford, B.A. 2 Old Palace-yard, Westminster, S.W.
1883. ‡Barlow, J. J. 37 Park-street, Southport.
1878. ‡Barlow, John, M.D., Professor of Physiology in Anderson's College, Glasgow.
1883. ‡Barlow, John R. Greenthorne, near Bolton.
Barlow, Lieut.-Col. Maurice (14th Regt. of Foot). 5 Great George-street, Dublin.
1885. §Barlow, William. Hillfield, Muswell Hill, London, N.
1873. §BARLOW, WILLIAM HENRY, F.R.S., M.Inst.C.E. 2 Old Palace-yard, Westminster, S.W.
1861. *Barnard, Major R. Cary, F.L.S. Bartlow, Leckhampton, Cheltenham.
1881. ‡Barnard, William, LL.B. Harlow, Essex.
1868. §Barnes, Richard H. Heatherlands, Parkstone, Dorset.
Barnes, Thomas Addison. Brampton Collieries, near Chesterfield.
1839. *Barnett, Richard, M.R.C.S. 35 Lansdowne-crescent, Great Malvern.
1884. §Barnett, I. D. Port Hope, Ontario.
1881. ‡Barr, Archibald, B.Sc., Professor of Civil and Mechanical Engineering in the Yorkshire College, Leeds.
1859. ‡Barr, Lieut.-General. Apsleytoun, East Grinstead, Sussex.
1883. ‡Barrett, John Chalk. Errismore, Birkdale, Southport.
1883. ‡Barrett, Mrs. J. C. Errismore, Birkdale, Southport.
1860. ‡Barrett, T. B. High-street, Welshpool, Montgomery.

Year of Election.

1872. *Barrett, W. F., F.R.S.E., M.R.I.A., Professor of Physics in the Royal College of Science, Dublin.
1883. ‡Barrett, William Scott. Winton Lodge, Crosby, near Liverpool.
1874. *Barrington, R. M. Fassaroe, Bray, Co. Wicklow.
1874. §Barrington-Ward, Mark J., M.A., F.L.S., F.R.G.S., H.M. Inspector of Schools. Thorneloe Lodge, Worcester.
1885. *Barron, Frederick Cadogan, M.Inst.C.E. The Priory, Bromley, Kent.
1881. §Barron, G. B., M.D. Summerseat, Southport.
1866. ‡Barron, William. Elvaston Nurseries, Borrowash, Derby.
1862. *Barry, Charles. 15 Pembridge-square, London, W.
1883. ‡Barry, Charles E. 15 Pembridge-square, London, W.
1875. ‡Barry, John Wolfe. 23 Delahay-street, Westminster, S.W.
1881. ‡Barry, J. W. Duncombe-place, York.
1884. *Barstow, Miss Frances. Garrow Hill, near York.
1858. *Bartholomew, Charles. Castle Hill House, Ealing, Middlesex, W.
1858. *Bartholomew, William Hamond. Ridgeway House, Cumberland-road, Headingley, Leeds.
1884. ‡Bartlett, James Herbert. 148 Mansfield-street, Montreal, Canada.
1873. ‡Bartley, George C. T., M.P. St. Margaret's House, Victoria-street, London, S.W.
1868. *Barton, Edward (27th Inniskillens). Clonelly, Ireland.
1884. ‡Barton, H. M. Foster-place, Dublin.
1852. ‡Barton, James. Farndreg, Dundalk.
1864. ‡Bartrum, John S. 41 Gay-street, Bath.
*Bashforth, Rev. Francis, B.D. Minting Vicarage, near Horncastle.
1876. ‡Bassano, Alexander. 12 Montagu-place, London, W.
1876. ‡Bassano, Clement. Jesus College, Cambridge.
1866. *Bassett, Henry. 26 Belitha-villas, Barnsbury, London, N.
1884. *Bassnett, Thomas. Box 335, Jacksonville, Florida, U.S.A.
1884. ‡Bassnett, Mrs. Thomas. Box 335, Jacksonville, Florida, U.S.A.
1869. ‡Bastard, S. S. Summerland-place, Exeter.
1871. ‡Bastian, H. Charlton, M.D., M.A., F.R.S., F.L.S., Professor of Pathological Anatomy at University College, London. 20 Queen Anne-street, London, W.
1848. ‡Bate, C. Spence, F.R.S., F.L.S. 8 Mulgrave-place, Plymouth.
1883. ‡Bateman, A. E. Board of Trade, London, S.W.
1873. *Bateman, Daniel. Carpenter-street, above Broad-street, Philadelphia, United States.
1868. ‡Bateman, Frederick, M.D. Upper St. Giles's-street, Norwich.
Bateman, James, M.A., F.R.S., F.R.G.S., F.L.S. Home House, Worthing.
1842. *Bateman, John Frederic La Trobe, F.R.S., F.G.S., F.R.G.S., M.Inst.C.E. 16 Great George-street, London, S.W.
1864. ‡Bates, Henry Walter, F.R.S., F.L.S., Assist.-Sec. R.G.S. 1 Savile-row, London, W.
1852. ‡Bateson, Sir Robert, Bart. Belvoir Park, Belfast.
1884. ‡Bateson, William, B.A. St. John's College, Cambridge.
1851. ‡Bath and Wells, The Right Rev. Lord Arthur Hervey, Lord Bishop of. The Palace, Wells, Somerset.
1881. *Bather, Francis Arthur. Red House, Roehampton, Surrey, S.W.
1836. ‡Batten, Edmund Chisholm. 25 Thurloe-square, London, S.W.
1869. ‡Batten, John Winterbotham. 35 Palace Gardens-terrace, Kensington, London, W.
1863. §Bauerman, H., F.G.S. 41 Acre-lane, Brixton, London, S.W.
1861. ‡Baxendell, Joseph, F.R.S., F.R.A.S. 14 Liverpool-road, Birkdale, Southport.

Year of Election.

1867. ‡Baxter, Edward. Hazel Hall, Dundee.
1867. ‡Baxter, The Right Hon. William Edward, M.P. Ashcliffe, Dundee.
1868. ‡Bayes, William, M.D. 58 Brook-street, London, W.
1866. ‡Bayley, Thomas. Lenton, Nottingham.
Bayly, John. Seven Trees, Plymouth.
1875. *Bayly, Robert. Torr-grove, near Plymouth.
1876. *BAYNES, ROBERT E., M.A. Christ Church, Oxford.
1883. *Bazley, Gardner. Hatherop Castle, Fairford, Gloucestershire.
Bazley, Sir Thomas Sebastian, Bart., M.A. Hatherop Castle, Fairford, Gloucestershire.
1860. *BEALE, LIONEL S., M.D., F.R.S., Professor of the Principles and Practice of Medicine in King's College, London. 61 Grosvenor-street, London, W.
1882. §Beamish, Major A. W., R.E. Cranbury-terrace, Southampton.
1884. ‡Beamish, G. H. M. Prison, Liverpool.
1872. ‡Beanes, Edward, F.C.S. Moatlands, Paddock Wood, Brenchley, Kent.
1870. ‡Beard, Rev. Charles. 13 South-hill-road, Toxteth Park, Liverpool.
1883. ‡Beard, Mrs. 13 South-hill-road, Toxteth Park, Liverpool.
*Beatson, William. Ash Mount, Rotherham.
1855. *Beaufort, W. Morris, F.R.A.S., F.R.G.S., F.R.M.S., F.S.S. 18 Piccadilly, London, W.
1861. *Beaumont, Rev. Thomas George. Chelmondiston Rectory, Ipswich.
1885. §Beaumont, W. W. 163 Strand, London, W.C.
1871. *Beazley, Lieut.-Colonel George G. 74 Redcliffe-square, London, S.W.
1859. *Beck, Joseph, F.R.A.S. 68 Cornhill, London, E.C.
1864. §Becker, Miss Lydia E. 155 Shrewsbury-street, Whalley Range, Manchester.
1860. ‡BECKLES, SAMUEL H., F.R.S., F.G.S. 9 Grand-parade, St. Leonard's-on-Sea.
1885. §Beddard, Frank E., M.A., F.Z.S., Prosector to the Zoological Society of London. Society's Gardens, Regent's Park, London, N.W.
1866. ‡Beddard, James. Derby-road, Nottingham.
1870. §BEDDOE, JOHN, M.D., F.R.S. Clifton, Bristol.
1858. ‡Bedford, James. Woodhouse Cliff, near Leeds.
1878. ‡BEDSON, P. PHILLIPS, D.Sc., F.C.S. College of Physical Science, Newcastle-on-Tyne.
1884. ‡Beers, W. G., M.D. 34 Beaver Hall-terrace, Montreal, Canada.
1873. ‡Behrens, Jacob. Springfield House, North-parade, Bradford, Yorkshire.
1874. ‡Belcher, Richard Boswell. Blockley, Worcestershire.
1873. ‡Bell, Asahel P. 32 St. Anne's-street, Manchester.
1871. §Bell, Charles B. 6 Spring-bank, Hull.
1884 ‡Bell, Charles Napier. Winnipeg, Canada.
Bell, Frederick John. Woodlands, near Maldon, Essex.
1860. ‡Bell, Rev. George Charles, M.A. Marlborough College, Wilts.
1880. §Bell, Henry Oswin. 13 Northumberland-terrace, Tynemouth.
1879. ‡*Bell, Henry S. Kenwood Bank, Sharrow, Sheffield.*
1862. *BELL, Sir ISAAC LOWTHIAN, Bart., F.R.S., F.C.S., M.Inst.C.E. Rounton Grange, Northallerton.
1875. ‡Bell, James, Ph.D., F.R.S., F.C.S. The Laboratory, Somerset House, London, W.C.
1871. *Bell, J. Carter, F.C.S. Bankfield, The Cliff, Higher Broughton, Manchester.
1883. *Bell, John Henry. Dalton Lees, Huddersfield.

Year of Election.

1853. ‡Bell, John Pearson, M.D. Waverley House, Hull.
1864. ‡Bell, R. Queen's College, Kingston, Canada.
1876. ‡Bell, R. Bruce, M.Inst.C.E. 203 St. Vincent-street, Glasgow.
1863. *Bell, Thomas. Palazio Vitoria, Bilbao, Spain.
1867. ‡Bell, Thomas. Belmont, Dundee.
1882. ‡Bell, W. Alexander, B.A. 3 Madeira-terrace, Kemp Town, Brighton.
1842. Bellhouse, Edward Taylor. Eagle Foundry, Manchester.
Bellingham, Sir Alan. Castle Bellingham, Ireland.
1882. §Bellingham, William. 15 Killieser-avenue, Telford Park, Streatham Hill, London, S.W.
1884. ‡Bemrose, Joseph. 15 Plateau-street, Montreal, Canada.
1864. *Bendyshe, T. 3 Sea View-terrace, Margate.
1885. §BENHAM, WILLIAM BLAXLAND, B.Sc. 34 Belsize-road, London, N.W.
1870. ‡BENNETT, ALFRED W., M.A., B.Sc., F.L.S. 6 Park Village East, Regent's Park, London, N.W.
1836. §Bennett, Henry. Bedminster, Bristol.
1881. §Bennett, John R. Bedminster, Bristol.
1883. *Bennett, Laurence Henry. Trinity College, Oxford.
1881. ‡Bennett, Rev. S. H., M.A. St. Mary's Vicarage, Bishophill Junior, York.
1870. *Bennett, William. Heysham Tower, Lancaster.
1870. *Bennett, William, jun. Oak Hill Park, Old Swan, near Liverpool.
1852. *Bennoch, Francis, F.S.A. 5 Tavistock-square, London, W.C.
1848. ‡Benson, Starling, F.G.S. Gloucester-place, Swansea.
1870. ‡Benson, W. Alresford, Hants.
1863. ‡Benson, William. Fourstones Court, Newcastle-on-Tyne.
1885. *Bent, J. Theodore. 13 Great Cumberland-place, London, W.
1884. ‡Bentham, William. 724 Sherbrooke-street, Montreal, Canada.
1842. *Bentley John. 2 Portland-place, London, W.*
1863. §BENTLEY, ROBERT, F.L.S., Professor of Botany in King's College, London. 38 Penywern-road, Earl's Court, London, S.W.
1876. ‡Bergius, Walter C. 9 Loudon-terrace, Hillhead, Glasgow.
1868. ‡BERKELEY, Rev. M. J., M.A., F.R.S., F.L.S. Sibbertoft, Market Harborough.
1863. ‡Berkley, C. Marley Hill, Gateshead, Durham.
1870. ‡Berwick, George, M.D. 36 Fawcett-street, Sunderland.
1862. ‡Besant, William Henry, M.A., D.Sc., F.R.S. St. John's College, Cambridge.
1865. *BESSEMER, Sir HENRY, F.R.S. Denmark Hill, London, S.E.
1882. *Bessemer, Henry, jun. Mount House, Hythe, Southampton.
1858. ‡Best, William. Leydon-terrace, Leeds.
Bethune, Admiral, C.B., F.R.G.S. Balfour, Fifeshire.
1883. ‡Betley, Ralph, F.G.S. Mining School, Wigan.
1876. *Bettany, G. T., M.A., B.Sc., Lecturer on Botany at Guy's Hospital, London. 2 Eckington-villas, Ashbourne-grove, East Dulwich, S.E.
1883. ‡Bettany, Mrs. 2 Eckington-villas, Ashbourne-grove, East Dulwich, S.E.
1880. *Bevan, Rev. James Oliver, M.A. The Vicarage, Vowchurch, Hereford.
1859. ‡Beveridge, Robert, M.B. 36 King-street, Aberdeen.
1885. §Beveridge, R. Beath Villa, Ferryhill, Aberdeen.
1884. *Beverley, Michael, M.D. 52 St. Giles'-street, Norwich.
1874. *Bevington, James B. Merle Wood, Sevenoaks.
1863. ‡Bewick, Thomas John, F.G.S. Suffolk House, Laurence Pountney Hill, London, E.C.

Year of Election.

*Bickerdike, Rev. John, M.A. Shireshead Vicarage, Garstang.
1870. ‡Bickerton, A.W., F.C.S. Christchurch, Canterbury, New Zealand.
1885. *Bidwell, Shelford, M.A., LL.B. Riverstone Lodge, Southfields, Wandsworth, Surrey, S.W.
1863. ‡Bigger, Benjamin. Gateshead, Durham.
1882. §Biggs, C. H. W., F.C.S. 1 Bloomfield, Bromley, Kent.
1864. ‡Biggs, Robert. 16 Green Park, Bath.
Bilton, Rev. William, M.A., F.G.S. United University Club, Suffolk-street, London, S.W.
1884. *Bingham, John E. Electric Works, Sheffield.
1881. ‡Binnie, Alexander R., F.G.S. Town Hall, Bradford, Yorkshire.
1873. ‡Binns, J. Arthur. Manningham, Bradford, Yorkshire.
1879. ‡Binns, E. Knowles, F.R.G.S. 216 Heavygate-road, Sheffield.
Birchall, Edwin, F.L.S. Douglas, Isle of Man.
1880. ‡Bird, Henry, F.C.S. South Down, near Devonport.
1866. *Birkin, Richard. Aspley Hall, near Nottingham.
1871. *Bischof, Gustav. 4 Hart-street, Bloomsbury, London, W.C.
1868. ‡Bishop, John. Thorpe Hamlet, Norwich.
1883. ‡Bishop, John le Marchant. 100 Mosley-street, Manchester.
1866. ‡Bishop, Thomas. Bramcote, Nottingham.
1885. §Bissett, J. P. Wyndem, Banchory, N.B.
1877. ‡Blachford, The Right Hon. Lord, K.C.M.G. Cornwood, Ivybridge.
1884. ‡Black, Francis, F.R.G.S. Edinburgh.
1881. §Black, William Galt, F.R.C.S.E. Caledonian United Service Club, Edinburgh.
1869. ‡Blackall, Thomas. 13 Southernhay, Exeter.
1876. ‡Blackburn, Hugh, M.A. Roshven, Fort William, N.B.
1884. ‡Blackburn, Robert. New Edinburgh, Ontario, Canada.
Blackburne, Rev. John, M.A. Yarmouth, Isle of Wight.
Blackburne, Rev. John, jun., M.A. Rectory, Horton, near Chippenham.
1877. ‡Blackie, J. Alexander. 17 Stanhope-street, Glasgow.
1859. ‡Blackie, John Stewart, M.A., Professor of Greek in the University of Edinburgh.
1876. ‡Blackie, Robert. 7 Great Western-terrace, Glasgow.
1855. *Blackie, W. G., Ph.D., F.R.G.S. 17 Stanhope-street, Glasgow.
1884. ‡Blacklock, Frederick W. 25 St. Famille-street, Montreal, Canada.
1883. ‡Blacklock, Mrs. Sea View, Lord-street, Southport.
1884. ‡Blaikie, James, M.A. 14 Viewforth-place, Edinburgh.
1878. §Blair, Matthew. Oakshaw, Paisley.
1883. §Blair, Mrs. Oakshaw, Paisley.
1863. ‡Blake, C. Carter, D.Sc. Westminster Hospital School of Medicine, Broad Sanctuary, Westminster, S.W.
1849. *Blake, Henry Wollaston, M.A., F.R.S., F.R.G.S. 8 Devonshire-place, Portland-place, London, W.
1883. *Blake, Rev. J. F., M.A., F.G.S., Professor of Natural Science in University College, Nottingham.
1846. *Blake, William. Bridge House, South Petherton, Somerset.
1878. ‡Blakeney, Rev. Canon, M.A., D.D. The Vicarage, Sheffield.
1861. §Blakiston, Matthew, F.R.G.S. Free Hills, Burledon, Hants.
1881. §Blamires, Thomas H. Close Hill, Lockwood, near Huddersfield.
1884. *Blandy, William Charles, B.A. 1 Friar-street, Reading.
1869. ‡Blanford, W. T., LL.D., F.R.S., Sec. G.S., F.R.G.S. 72 Bedford-gardens, Campden Hill, London, W.
1884. *Blish, William G. Niles, Michigan, U.S.A.
1869. *Blomefield, Rev. Leonard, M.A., F.L.S., F.G.S. 19 Belmont, Bath.

Year of Election.

1880. §Bloxam, G. W., M.A., F.L.S. 11 Chalcot-crescent, Regent's Park, London, N.W.
1883. ‡Blumberg, Dr. 65 Hoghton-street, Southport.
1870. ‡Blundell, Thomas Weld. Ince Blundell Hall, Great Crosby, Lancashire.
1859. ‡Blunt, Sir Charles, Bart. Heathfield Park, Sussex.
1859. ‡Blunt, Captain Richard. Bretlands, Chertsey, Surrey.
1885. §Blyth, James, M.A., F.R.S.E. Anderson's College, Glasgow.
Blyth, B. Hall. 135 George-street, Edinburgh.
1883. ‡Blyth, Miss Phœbe. 3 South Mansion House-road, Edinburgh.
1858. *Blythe, William. Holland Bank, Church, near Accrington.
1867. ‡Blyth-Martin, W. Y. Blyth House, Newport, Fife.
1870. ‡Boardman, Edward. Queen-street, Norwich.
1883. ‡Bodman, Miss Caroline M. 45 Devonshire-street, Portland-place, London, W.
1884. ‡Body, Rev. C. W. E., M.A. Trinity College, Toronto, Canada.
1871. ‡Bohn, Mrs. North End House, Twickenham.
1881. ‡Bojanowski, Dr. Victor de, Consul-General for Germany. 27 Finsbury-circus, London, E.C.
1876. ‡Bolton, J. C. Carbrook, Stirling.
1866. ‡*Bond, Banks. Low Pavement, Nottingham.*
Bond, Henry John Hayes, M.D. Cambridge.
1883. §Bonney, Frederic, F.R.G.S. Oriental Club, Hanover-square, London, W.
1883. §Bonney, Miss S. 23 Denning-road, Hampstead, London, N.W.
1871. *Bonney, Rev. Thomas George, D.Sc., LL.D., F.R.S., F.S.A., F.G.S., Professor of Geology in University College, London. 23 Denning-road, London, N.W.
1866. ‡Booker, W. H. Cromwell-terrace, Nottingham.
1861. ‡Booth, James. Elmfield, Rochdale.
1883. §Booth, James. Hazelhurst House, Turton.
1883. ‡Booth, Richard. 4 Stone-buildings, Lincoln's Inn, London, W.C.
1876. ‡*Booth, Rev. William H. Yardley, Birmingham.*
1883. §Boothroyd, Benjamin. Rawlinson-road, Southport.
1880. ‡Boothroyd, Samuel. Warley House, Southport.
1861. *Borchardt, Louis, M.D. Barton Arcade, Manchester.
1849. ‡Boreham, William W., F.R.A.S. The Mount, Haverhill, Newmarket.
1876. *Borland, William. 260 West George-street, Glasgow.
1882. ‡Borns, Henry, Ph.D., F.C.S. 51 Merton-road, Wimbledon, Surrey.
1876. *Bosanquet, R. H. M., M.A., F.C.S., F.R.A.S. St. John's College, Oxford.
*Bossey, Francis, M.D. Mayfield, Oxford-road, Redhill, Surrey.
1881. §Bothamley, Charles H. Yorkshire College, Leeds.
1867. §Botly, William, F.S.A. Salisbury House, Hamlet-road, Upper Norwood, London, S.E.
1872. ‡Bottle, Alexander. Dover.
1868. ‡Bottle, J. T. 28 Nelson-road, Great Yarmouth.
1871. *Bottomley, James Thomson, M.A., F.R.S.E., F.C.S. 13 University-gardens, Glasgow.
1884. *Bottomley, Mrs. 13 University-gardens, Glasgow.
Bottomley, William. 11 Delamere-street, London, W.
1876. ‡Bottomley, William, jun. 6 Rokeley-terrace, Hillhead, Glasgow.
1870. ‡Boult, Swinton. 1 Dale-street, Liverpool.
1883. §Bourdas, Isaiah. 59 Belgrave-road, London, S.W.

Year of Election.

1883. †Bourne, A. G., D.Sc., F.L.S., Professor of Zoology in the Presidency College, Madras.
1866. §Bourne, Stephen, F.S.S. Abberley, Wallington, Surrey.
1884. §Bovey, Henry T., M.A., Professor of Civil Engineering and Applied Mechanics in McGill College, Montreal. Ontario-avenue, Montreal, Canada.
1872. ‡*Bovill, William Edward. 29 James-street, Buckingham-gate, London, S.W.*
1870. ‡Bower, Anthony. Bowersdale, Seaforth, Liverpool.
1881. *Bower, F. O. Elmscroft, Ripon, Yorkshire.
1867. ‡Bower, Dr. John. Perth.
1856. *Bowlby, Miss F. E. 23 Lansdowne-parade, Cheltenham
1884. §Bowley, Edwin. Burnt Ash Hill, Lee, Kent.
1880. ‡Bowly, Christopher. Cirencester.
1863. ‡Bowman, R. Benson. Newcastle-on-Tyne.
Bowman, Sir William, Bart., M.D., LL.D., F.R.S., F.R.C.S. 5 Clifford-street, London, W.
1869. ‡Bowring, Charles T. Elmsleigh, Prince's-park, Liverpool.
1863. ‡Boyd, Edward Fenwick. Moor House, near Durham.
1884. *Boyd, M. A., M.D. 30 Merrion-square, Dublin.
1871. ‡Boyd, Thomas J. 41 Moray-place, Edinburgh.
1865. ‡Boyle, The Very Rev. G. D., M.A., Dean of Salisbury. The Deanery, Salisbury.
1884. *Boyle, R. Vicars, C.S.I. Care of Messrs. Grindlay & Co., 55 Parliament-street, London, S.W.
1872. *Brabrook, E. W., F.S.A. 28 Abingdon-street, Westminster, S.W.
1869. *Braby, Frederick, F.G.S., F.C.S. Bushey Lodge, Teddington, Middlesex.
1884. *Brace, W. H., M.D. 7 Queen's Gate-terrace, London, S.W.
1880. ‡Bradford, H. Stretton House, Walters-road, Swansea.
1857. *Brady, Cheyne, M.R.I.A. Trinity Vicarage, West Bromwich.
1863. ‡Brady, George S., M.D., F.R.S., F.L.S., Professor of Natural History in the College of Physical Science, Newcastle-on-Tyne 22 Fawcett-street, Sunderland.
1862. ‡Brady, Henry Bowman, F.R.S., F.L.S., F.G.S. 6 Harley-place, Clifton, Bristol.
1880. *Brady, Rev. Nicholas, M.A. Wennington, Essex.
1864. §Braham, Philip, F.C.S. Bath.
1870. ‡Braidwood, Dr. Delemere-terrace, Birkenhead.
1879. ‡Bramley, Herbert. Claremont-crescent, Sheffield.
1865. §Bramwell, Sir Frederick J., LL.D., F.R.S., Pres. Inst.C.E. 5 Great George-street, London, S.W.
1872. ‡Bramwell, William J. 17 Prince Albert-street, Brighton.
1867. ‡Brand, William. Milnefield, Dundee.
1861. *Brandreth, Rev. Henry. Dickleburgh Rectory, Scole, Norfolk.
1885. *Bratby, W. Pott-street, Ancoats, Manchester.
1852. ‡Brazier, James S., F.C.S., Professor of Chemistry in Marischal College and University of Aberdeen.
1869. *Breadalbane, The Right Hon. the Earl of. Taymouth Castle, N.B.; and Carlton Club, Pall Mall, London, S.W.
1868. ‡Bremridge, Elias. 17 Bloomsbury-square, London, W.C.
1877. ‡Brent, Francis. 19 Clarendon-place, Plymouth.
1882. *Bretherton, C. E. 6 King's Bench-walk, Temple, London, E.C.
1881. *Brett, Alfred Thomas, M.D. Watford House, Watford.
1866. ‡Brettell, Thomas (Mine Agent). Dudley.
1875. ‡Briant, T. Hampton Wick, Kingston-on-Thames.
1884. ‡Bridges, C. J. Winnipeg, Canada.

Year of Election.

1867. ‡Bridgman, William Kenceley. 69 St. Giles's-street, Norwich.
1870. *Bridson, Joseph R. Sawrey, Windermere.
1870. ‡Brierley, Joseph, C.E. New Market-street, Blackburn.
1879. ‡Brierley, Morgan. Denshaw House, Saddleworth.
1870. *Brigg, John. Broomfield, Keighley, Yorkshire.
1866. *Briggs, Arthur. Cragg Royd, Rawdon, near Leeds.
1863. *Bright, Sir Charles Tilston, M.Inst.C.E., F.G.S., F.R.G.S., F.R.A.S. 20 Bolton-gardens, London, S.W.
1870. ‡Bright, H. A., M.A., F.R.G.S. Ashfield, Knotty Ash.
Bright, The Right Hon. John, M.P. Rochdale, Lancashire.
1868. ‡Brine, Captain Lindesay, F.R.G.S. United Service Club, Pall Mall, London, S.W.
1884. ‡Brisette, M. H. 424 St. Paul-street, Montreal, Canada.
1879. ‡Brittain, Frederick. Taptonville-crescent, Sheffield.
1879. *Brittain, W. H. Storth Oaks, Ranmoor, Sheffield.
1878. ‡Britten, James, F.L.S. Department of Botany, British Museum, London, W.C.
1884. *Brittle, John R., M.Inst.C.E., F.R.S.E. Farad Villa, Vanbrugh Hill, Blackheath, London, S.E.
1859. *Brodhurst, Bernard Edward, F.R.C.S., F.L.S. 20 Grosvenor-street, Grosvenor-square, London, W.
1883. *Brodie, David, M.D. Beverly House, St. Thomas' Hill, Canterbury.
1865. ‡Brodie, Rev. Peter Bellinger, M.A., F.G.S. Rowington Vicarage, near Warwick.
1884. ‡Brodie, William, M.D. 64 Lafayette-avenue, Detroit, Michigan, U.S.A.
1878. *Brook, George, F.L.S. Fernbrook, Huddersfield, Yorkshire.
1880. ‡Brook, G. B. Brynsyfi, Swansea.
1881. §Brook, Robert G. Rowen-street, St. Helen's, Lancashire.
1855. ‡Brooke, Edward. Marsden House, Stockport, Cheshire.
1864. *Brooke, Rev. J. Ingham. Thornhill Rectory, Dewsbury.
1855. ‡Brooke, Peter William. Marsden House, Stockport, Cheshire.
1878. ‡Brooke, Sir Victor, Bart., F.L.S. Colebrook, Brookeborough, Co. Fermanagh.
1863. ‡Brooks, John Crosse. Wallsend, Newcastle-on-Tyne.
1846. *Brooks, Thomas. Cranshaw Hall, Rawtenstall, Manchester.
1847. ‡Broome, C. Edward, F.L.S. Elmhurst, Batheaston, near Bath.
1883. §Brotherton, E. A. Bolton Bridge-road, Ilkley, Leeds.
1885. *Browett, Alfred. 14 Dean-street, Birmingham.
1863. *Brown, Alexander Crum, M.D., F.R.S. L. & E., F.C.S., Professor of Chemistry in the University of Edinburgh. 8 Belgrave-crescent, Edinburgh.
1867. ‡Brown, Charles Gage, M.D. 88 Sloane-street, London, S.W.
1855. ‡Brown, Colin. 192 Hope-street, Glasgow.
1871. ‡Brown, David. 93 Abbey-hill, Edinburgh.
1863. *Brown, Rev. Dixon. Unthank Hall, Haltwhistle, Carlisle.
1883. ‡Brown, Mrs. Ellen F. Campbell. 27 Abercromby-square, Liverpool.
1881. ‡Brown, Frederick D. 26 St. Giles's-street, Oxford.
1883. ‡Brown, George Dransfield. Henley Villa, Ealing, Middlesex. W.
1884. ‡Brown, Gerald Culmer. Lachute, Quebec, Canada.
1883. §Brown, Mrs. H. Bientz. 50 Effingham-road, Lee, Kent.
1884. §Brown, Harry. University College, London, W.C.
1883. ‡Brown, Mrs. Helen. 52 Grange Loan, Edinburgh.
1870. §Brown, Horace T. 47 High-street, Burton-on-Trent.
Brown, Hugh. Broadstone, Ayrshire.
1883. ‡Brown, Miss Isabella Spring. 52 Grange Loan, Edinburgh.

Year of Election.

1870. *Brown, Professor J. Campbell, D.Sc., F.C.S. University College, Liverpool.
1876. §Brown, John. Edenderry House, Belfast.
1881. *Brown, John, M.D. 66 Bank-parade, Burnley, Lancashire.
1882. *Brown, John. Swiss Cottage, Park-valley, Nottingham.
1859. ‡Brown, Rev. John Crombie, LL.D., F.L.S. Haddington, N.B.
1874. ‡Brown, John S. Edenderry, Shaw's Bridge, Belfast.
1882. *Brown, Mrs. Mary. Burnley, Lancashire.
1885. §Brown, Miss. Springfield House, Ilkley, Yorkshire.
1863. ‡Brown, Ralph. Lambton's Bank, Newcastle-on-Tyne.
1871. ‡Brown, Robert, M.A., Ph.D., F.L.S., F.R.G.S. Fersley, Rydal-road, Streatham, London, S.W.
1868. ‡Brown, Samuel. Grafton House, Swindon, Wilts.
1850. ‡Brown, William, F.R.S.E. 25 Dublin-street, Edinburgh.
1865. ‡Brown, William. 41a New-street, Birmingham.
1884. §Brown, William George. Ivy, Albemarle Co., Virginia, U.S.A.
1885. §Brown, W. A. The Court House, Aberdeen.
1879. ‡Browne, J. Crichton, M.D., LL.D., F.R.S. L. & E. 7 Cumberland-terrace, Regent's Park, London, N.W.
1866. *Browne, Rev. J. H. Lowdham Vicarage, Nottingham.
1862. *Browne, Robert Clayton, jun., B.A. Browne's Hill, Carlow, Ireland.
1872. ‡Browne, R. Mackley, F.G.S. Redcot, Bradbourne, Sevenoaks, Kent.
1865. *Browne, William, M.D. Heath Wood, Leighton Buzzard.
1865. ‡Browning, John, F.R.A.S. 63 Strand, London, W.C.
1883. ‡Browning, Oscar, M.A. King's College, Cambridge.
1855. ‡Brownlee, James, jun. 30 Burnbank-gardens, Glasgow.
1863. *Brunel, H. M. 23 Delahay-street, Westminster, S.W.
1863. ‡Brunel, J. 23 Delahay-street, Westminster, S.W.
1875. *Brunlees, James, F.R.S.E., F.G.S., M.Inst.C.E. 5 Victoria-street, Westminster, S.W.
1875. ‡Brunlees, John. 5 Victoria-street, Westminster, S.W.
1868. ‡Brunton, T. Lauder, M.D., D.Sc., F.R.S. 50 Welbeck-street, London, W.
1878. §Brutton, Joseph. Yeovil.
1877. ‡Bryant, George. 82 Claverton-street, Pimlico, London, S.W.
1875. ‡*Bryant, G. Squier. 15 White Ladies'-road, Clifton, Bristol.*
1884. ‡Bryce, Rev. Professor George. The College, Manitoba, Canada.
Bryce, Rev. R. J., LL.D. Fitzroy-avenue, Belfast.
1859. ‡Bryson, William Gillespie. Cullen, Aberdeen.
1871. §Buchan, Alexander, M.A., F.R.S.E., Sec. Scottish Meteorological Society. 72 Northumberland-street, Edinburgh.
1867. ‡Buchan, Thomas. Strawberry Bank, Dundee.
1885. *Buchan, William Paton. Fairyknowe, Cambuslang, N.B.
Buchanan, Archibald. Catrine, Ayrshire.
Buchanan, D. C. 12 Barnard-road, Birkenhead, Cheshire.
1881. *Buchanan, John H., M.D. Sowerby, Thirsk.
1871. ‡Buchanan, John Young. 10 Moray-place, Edinburgh.
1884. ‡Buchanan, W. Frederick. Winnipeg, Canada.
1883. §Buckland, Miss A. W. 54 Doughty-street, London, W.C.
1864. §Buckle, Rev. George, M.A. The Rectory, Weston-super-Mare.
1865. *Buckley, Henry. 27 Wheeley's-road, Edgbaston, Birmingham.
1880. §Buckney, Thomas, F.R.A.S. Delhi House, Coventry Park, Streatham, S.W.
1869. ‡Bucknill, J. C., M.D., F.R.S. E 2 Albany, London, W.
1884. *Buckmaster, Charles Alexander, M.A., F.C.S. Science and Art Department, South Kensington, London, S.W.

Year of Election.

1851. *BUCKTON, GEORGE BOWDLER, F.R.S., F.L.S., F.C.S. Weycombe, Haslemere, Surrey.
1875. §Budgett, Samuel. Cotham House, Bristol.
1883. ‡Buick, Rev. George R., M.A. Cullybackey, Co. Antrim, Ireland.
1871. ‡Bulloch, Matthew. 4 Bothwell-street, Glasgow.
1881. ‡Bulmer, T. P. Mount-villas, York.
1883. ‡Bulpit, Rev. F. W. Crossens Rectory, Southport.
1845. *BUNBURY, Sir CHARLES JAMES FOX, Bart., F.R.S., F.L.S., F.G.S., F.R.G.S. Barton Hall, Bury St. Edmunds.
1865. ‡Bunce, John Mackray. 'Journal' Office, New-street, Birmingham.
1863. §Bunning, T. Wood. Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
1842. *Burd, John. 5 Gower-street, London, W.C.
1875. ‡Burder, John, M.D. 7 South-parade, Bristol.
1869. ‡Burdett-Coutts, Baroness. 1 Stratton-street, Piccadilly, London, W.
1881. ‡Burdett-Coutts, W. L. A. B., M.P. 1 Stratton-street, Piccadilly, London, W.
1884. *Burland, Jeffrey H. 287 University-street, Montreal, Canada.
1883. *Burne, Colonel Sir Owen Tudor, K.C.S.I., C.I.E., F.R.G.S. 57 Sutherland-gardens, Maida Vale, London, W.
1876. ‡Burnet, John. 14 Victoria-crescent, Dowanhill, Glasgow.
1885. *Burnett, W. Kendall. 123½ Union-street, Aberdeen.
1877. ‡Burns, David, C.E. Alston, Carlisle.
1884. §Burns, James Austin. Atlanta P.O., Box 456, Georgia, U.S.A.
1883. §Burr, Percy J. 20 Little Britain, London, E.C.
1881. §Burroughs, S. M. 7 Snow-hill, London, E.C.
1883. *Burrows, Abraham. Greenhall, Atherton, near Manchester.
1860. ‡Burrows, Montague, M.A., Professor of Modern History, Oxford.
1877. ‡Burt, J. Kendall. Kendal.
1874. ‡*Burt, Rev. J. T. Broadmoor, Berks.*
1866. *BURTON, FREDERICK M., F.G.S. Highfield, Gainsborough.
1864. ‡Bush, W. 7 Circus, Bath.
Bushell, Christopher. Royal Assurance-buildings, Liverpool.
1855. *BUSK, GEORGE, F.R.S., F.L.S., F.G.S. 32 Harley-street, Cavendish-square, London, W.
1878. ‡BUTCHER, J. G., M.A. 22 Collingham-place, London, S.W.
1884. *Butcher, William Deane, M.R.C.S.Eng. Clydesdale, Windsor.
1884. ‡Butler, Matthew I. Napanee, Ontario, Canada.
1884. *Butterworth, W. Greenhill, Church-lane, Harpurhey, Manchester.
1872. ‡Buxton, Charles Louis. Cromer, Norfolk.
1870. ‡Buxton, David, Ph.D. 298 Regent-street, London, W.
1883. ‡Buxton, Miss F. M. Newnham College, Cambridge.
1868. ‡Buxton, S. Gurney. Catton Hall, Norwich.
1881. ‡Buxton, Sydney. 7 Grosvenor-crescent, London, S.W.
1883. ‡Buxton, Rev. Thomas, M.A. 19 Westcliffe-road, Birkdale, Southport.
1872. ‡Buxton, Sir Thomas Fowell, Bart., F.R.G.S. Warlies, Waltham Abbey, Essex.
1854. ‡BYERLEY, ISAAC, F.L.S. Seacombe, Cheshire.
1885. §Byres, David. 63 North Bradford, Aberdeen.
1852. ‡Byrne, Very Rev. James. Ergenagh Rectory, Omagh.
1883. §Byrom, John R. Mere Bank, Fairfield, near Manchester.
1875. ‡Byrom, W. Ascroft, F.G.S. 31 King-street, Wigan.

1863. ‡Cail, Richard. Beaconsfield, Gateshead.
1858. *Caine, Rev. William, M.A. Christ Church Rectory, Denton, near Manchester.
1863. ‡Caird, Edward. Finnart, Dumbartonshire.

Year of Election.

1876. ‡Caird, Edward B. 8 Scotland-street, Glasgow.
1861. *Caird, James Key. 8 Magdalene-road, Dundee.
1855. *Caird, James Tennant. Belleaire, Greenock.
1875. ‡*Caldicott, Rev. J. W., D.D. The Grammar School, Bristol.*
1868. ‡Caley, A. J. Norwich.
1857. ‡Callan, Rev. N. J., Professor of Natural Philosophy in Maynooth College.
1854. ‡Calver, Captain E. K., R.N., F.R.S. 23 Park-place East, Sunderland, Durham.
1884. ‡Cameron, Æneas. Yarmouth, Nova Scotia, Canada.
1876. ‡Cameron, Charles, M.D., LL.D., M.P. 1 Huntly-gardens, Glasgow.
1857. ‡CAMERON, Sir CHARLES A., M.D. 15 Pembroke-road, Dublin.
1884. ‡Cameron, James C., M.D. 41 Belmont-park, Montreal, Canada.
1870. ‡Cameron, John, M.D. 17 Rodney-street, Liverpool.
1881. ‡Cameron, Major-General, C.B. 3 Driffield-terrace, York.
1884. ‡Campbell, Archibald H. Toronto, Canada.
1874. *CAMPBELL, Sir GEORGE, K.C.S.I., M.P., D.C.L., F.R.G.S., F.S.S. Southwell House, Southwell-gardens, South Kensington, London, S.W.; and Edenwood, Cupar, Fife.
1883. ‡Campbell, H. J. 81 Kirkstall-road, Talfourd Park, Streatham Hill, S.W.
Campbell, Sir Hugh P. H., Bart. 10 Hill-street, Berkeley-square, London, W.; and Marchmont House, near Dunse, Berwickshire.
1876. ‡Campbell, James A., LL.D., M.P. Stracathro House, Brechin.
Campbell, John Archibald, M.D., F.R.S.E. Albyn-place, Edinburgh.
1859. ‡Campbell, William. Dunmore, Argyllshire.
CAMPBELL-JOHNSTON, ALEXANDER ROBERT, F.R.S. 84 St. George's-square, London, S.W.
1876. ‡Campion, Frank, F.G.S., F.R.G.S. The Mount, Duffield-road, Derby.
1862. *CAMPION, Rev. WILLIAM M., D.D. Queen's College, Cambridge.
1882. ‡Candy, F. H. 71 High-street, Southampton.
1880. ‡Capper, Robert. Westbrook, Swansea.
1883. §Capper, Mrs. R. Westbrook, Swansea.
1873. *Carbutt, Edward Hamer, M.P., C.E. 19 Hyde Park-gardens, London, W.
*Carew, William Henry Pole. Antony, Torpoint, Devonport.
1883. §Carey-Hobson, Mrs. 54 Doughty-street, London, W.C.
1877. ‡Carkeet, John, C.E. 3 St. Andrew's-place, Plymouth.
1876. ‡Carlile, Thomas. 5 St. James's-terrace, Glasgow.
CARLISLE, The Right Rev. HARVEY GOODWIN, D.D., D.C.L., Lord Bishop of. Carlisle.
1861. ‡*Carlton, James. Mosley-street, Manchester.*
1867. ‡Carmichael, David (Engineer). Dundee.
1867. ‡Carmichael, George. 11 Dudhope-terrace, Dundee.
1876. ‡Carmichael, Neil, M.D. 22 South Cumberland-street, Glasgow.
1884. ‡Carnegie, John. Peterborough, Ontario, Canada.
1885. *CARNELLY, THOMAS, D.Sc., Professor of Chemistry in University College, Dundee.
1884. §Carpenter, Louis G. Agricultural College, Lansing, Michigan, U.S.A.
1871. *CARPENTER, P. HERBERT, D.Sc., F.R.S. Eton College, Windsor.
1854. ‡Carpenter, Rev. R. Lant, B.A. Bridport.
1872. §CARPENTER, WILLIAM LANT, B.A., B.Sc., F.C.S. 36 Craven-park, Harlesden, London, N.W.
1884. *Carpmael, Charles. Toronto, Canada.
1867. ‡CARRUTHERS, WILLIAM, F.R.S., F.L.S., F.G.S. British Museum, London, W.C.

Year of Election.

1883. §Carson, John. 51 Royal Avenue, Belfast.
1861. *Carson, Rev. Joseph, D.D., M.R.I.A. 18 Fitzwilliam-place, Dublin.
1868. ‡Carteighe, Michael, F.C.S. 172 New Bond-street, London, W.
1866. ‡Carter, H. H. The Park, Nottingham.
1855. ‡Carter, Richard, F.G.S. Cockerham Hall, Barnsley, Yorkshire.
1870. ‡Carter, Dr. William. 62 Elizabeth-street, Liverpool.
1883. ‡Carter, W. C. Manchester and Salford Bank, Southport.
1883. ‡Carter, Mrs. Manchester and Salford Bank, Southport.
1878. *Cartwright, E. Henry. Magherafelt Manor, Co. Derry.
1870. §Cartwright, Joshua, M.Inst.C.E., Borough Surveyor. Bury, Lancashire.
1862. ‡Carulla, Facundo. Care of Messrs. Daglish and Co., 8 Harrington-street, Liverpool.
1884. *Carver, Rev. Canon Alfred J., D.D., F.R.G.S. Lynnhurst, Streatham Common, London, S.W.
1884. §Carver, Mrs. Lynnhurst, Streatham Common, London, S.W.
1883. §Carver, James. Garfield House, Elm-avenue, Nottingham.
1868. ‡Cary, Joseph Henry. Newmarket-road, Norwich.
1866. ‡Casella, L. P., F.R.A.S. The Lawns, Highgate, London, N.
1878. ‡Casey, John, LL.D., F.R.S., M.R.I.A., Professor of Higher Mathematics in the Catholic University of Ireland. 86 South Circular-road, Dublin.
1871. ‡Cash, Joseph. Bird-grove, Coventry.
1873. *Cash, William, F.G.S. 38 Elmfield-terrace, Saville Park, Halifax.
Castle, Charles. Clifton, Bristol.
1874. ‡Caton, Richard, M.D., Lecturer on Physiology at the Liverpool Medical School. 18A Abercromby-square, Liverpool.
1859. ‡Catto, Robert. 44 King-street, Aberdeen.
1884. *Cave, Herbert. Christ Church, Oxford.
1849. ‡Cawley, Charles Edward. The Heath, Kirsall, Manchester.
1860. §Cayley, Arthur, M.A., D.C.L., LL.D., F.R.S., V.P.R.A.S., Sadlerian Professor of Pure Mathematics in the University of Cambridge. Garden House, Cambridge.
Cayley, Digby. Brompton, near Scarborough.
Cayley, Edward Stillingfleet. Wydale, Malton, Yorkshire.
1871. *Cecil, Lord Sackville. Hayes Common, Beckenham, Kent.
1879. §Chadburn, Alfred. Brincliffe Rise, Sheffield.
1870. ‡Chadburn, C. H. Lord-street, Liverpool.
1858. *Chadwick, Charles, M.D. Lynncourt, Broadwater Down, Tunbridge Wells.
1860. ‡Chadwick, David. The Poplars, Herne Hill, London, S.E.
1842. Chadwick, Edwin, C.B. Park Cottage, East Sheen, Middlesex, S.W.
1883. ‡Chadwick, James Percy. 51 Alexandra-road, Southport.
1859. ‡Chadwick, Robert. Highbank, Manchester.
1883. ‡Chalk, William. 24 Gloucester-road, Birkdale, Southport.
1859. ‡Chalmers, John Inglis. Aldbar, Aberdeen.
1883. ‡Chamberlain, George, J.P. Helensholme, Birkdale Park, Southport.
1884. ‡Chamberlain, Montague. St. John's, New Brunswick, Canada.
1883. ‡Chambers, Benjamin. Hawkshead-street South, Southport.
1883. ‡Chambers, Charles, F.R.S. Colába Observatory, Bombay.
1883. ‡Chambers, Mrs. Colába Observatory, Bombay.
1883. ‡Chambers, Charles, jun. The College, Cooper's Hill, Staines.
1842. Chambers, George. High Green, Sheffield.
1868. ‡Chambers, W. O. Lowestoft, Suffolk.
1877. *Champernowne, Arthur, M.A., F.G.S. Dartington Hall, Totnes, Devon.

Year of Election.

*Champney, Henry Nelson. 4 New-street, York.
1881. *Champney, John E. Woodlands, Halifax.
1865. ‡Chance, A. M. Edgbaston, Birmingham.
1865. *Chance, James T. 51 Prince's-gate, London, S.W.
1865. ‡Chance, Robert Lucas. Chad Hill, Edgbaston, Birmingham.
1861. *Chapman, Edward, M.A., F.L.S., F.C.S. Frewen Hall, Oxford.
1884. ‡Chapman, Professor. University College, Toronto, Canada.
1877. §Chapman, T. Algernon, M.D. Burghill, Hereford.
1871. ‡Chappell, William, F.S.A. Strafford Lodge, Oatlands Park, Weybridge Station.
1874. ‡Charles, John James, M.A., M.D. 11 Fisherwick-place, Belfast.
1836. CHARLESWORTH, EDWARD, F.G.S. 277 Strand, London, W.C.
1874. ‡Charley, William. Seymour Hill, Dunmurry, Ireland.
1866. ‡CHARNOCK, RICHARD STEPHEN, Ph.D., F.S.A., F.R.G.S. Junior Garrick Club, Adelphi-terrace, London, W.C.
1883. ‡Chater, Rev. John. Part-street, Southport.
1884. *Chatterton, George. 46 Queen Anne's-gate, London, S.W.
1867. *Chatwood, Samuel, F.R.G.S. Irwell House, Drinkwater Park, Prestwich.
1884. ‡CHAUVEAU, The Hon. Dr. Montreal, Canada.
1883. ‡Chawner, W., M.A. Emanuel College, Cambridge.
1864. ‡CHEADLE, W. B., M.A., M.D., F.R.G.S. 2 Hyde Park-place, Cumberland-gate, London, S.W.
1874. *Chermside, Lieutenant H. C., R.E., C.B. Care of Messrs. Cox & Co., Craig's-court, Charing Cross, London, S.W.
1884. ‡Cherriman, Professor J. B. Ottawa, Canada.
1879. *Chesterman, W. Broomsgrove-road, Sheffield.
1879. ‡*Cheyne, Commander J. P., R.N. 1 Westgate-terrace, West Brompton, London, S.W.*
CHICHESTER, The Right Rev. RICHARD DURNFORD, D.D., Lord Bishop of. Chichester.
1865. *Child, Gilbert W., M.A., M.D., F.L.S. Cowley House, Oxford.
1883. §Chinery, Edward F. Monmouth House, Lymington.
1884. ‡Chipman, W. W. L. 6 Place d'Armes, Ontario, Canada.
1842. *Chiswell, Thomas. 17 Lincoln-grove, Plymouth-grove, Manchester.
1863. ‡Cholmeley, Rev. C. H. Dinton Rectory, Salisbury.
1882. §Chorley, George. Midhurst, Sussex.
1861. ‡Christie, Professor R. C., M.A. 7 St. James's-square, Manchester.
1884. *Christie, William. 13 Queen's Park, Toronto, Canada.
1875. *Christopher, George, F.C.S. 8 Rectory-grove, Clapham, London, S.W.
1876. *CHRYSTAL, GEORGE, M.A., F.R.S.E., Professor of Mathematics in the University of Edinburgh. 5 Belgrave-crescent, Edinburgh.
1870. §CHURCH, A. H., M.A., F.C.S., Professor of Chemistry to the Royal Academy of Arts, London. Shelsley, Ennerdale-road, Kew, Surrey.
1860. ‡Church, William Selby, M.A. St. Bartholomew's Hospital, London, E.C.
1881. ‡Churchill, Lord Alfred Spencer. 16 Rutland-gate, London, S.W.
1857. ‡Churchill, F., M.D. Ardtrea Rectory, Stewartstown, Co. Tyrone.
1868. ‡Clabburn, W. H. Thorpe, Norwich.
1863. ‡Clapham, Henry. 5 Summerhill-grove, Newcastle-on-Tyne.
1869. *Clapp, Frederick. Roseneath, St. James's-road, Exeter.
1857. ‡Clarendon, Frederick Villiers. 1 Belvidere-place, Mountjoy-square, Dublin.

Year of Election.

1859. ‡Clark, David. Coupar Angus, Fifeshire.
1876. ‡Clark, David R., M.A. 31 Waterloo-street, Glasgow.
1877. *Clark, F. J. Street, Somerset.
1876. ‡Clark, George W. 31 Waterloo-street, Glasgow.
Clark, G. T. 44 Berkeley-square, London, W.
1876. ‡Clark, Dr. John. 138 Bath-street, Glasgow.
1881. ‡Clark, J. Edmund, B.A., B.Sc., F.G.S. 20 Bootham, York.
1861. ‡Clark, Latimer. 5 Westminster-chambers, Victoria-street, London, S.W.
1855. ‡Clark, Rev. William, M.A. Barrhead, near Glasgow.
1883. ‡Clarke, Rev. Canon, D.D. 59 Hoghton-street, Southport.
1865. ‡Clarke, Rev. Charles. Charlotte-road, Edgbaston, Birmingham.
1875. ‡Clarke, Charles S. 4 Worcester-terrace, Clifton, Bristol.
Clarke, George. Mosley-street, Manchester.
1872. *Clarke, Hyde. 32 St. George's-square, Pimlico, London, S.W.
1875. ‡Clarke, John Henry. 4 Worcester-terrace, Clifton, Bristol.
1861. *Clarke, John Hope. 45 Nelson-street, Chorlton-on-Medlock, Manchester.
1877. ‡Clarke, Professor John W. University of Chicago, Illinois, U.S.A.
1851. ‡Clarke, Joshua, F.L.S. Fairycroft, Saffron Walden.
Clarke, Thomas, M.A. Knedlington Manor, Howden, Yorkshire.
1883. ‡Clarke, W. P., J.P. 15 Hesketh-street, Southport.
1884. ‡Claxton, T. James. 461 St. Urbain-street, Montreal, Canada.
1861. ‡Clay, Charles, M.D. 101 Piccadilly, Manchester.
*Clay, Joseph Travis, F.G.S. Rastrick, near Brighouse, Yorkshire.
1856. *Clay, Colonel William. The Slopes, Wallasea, Cheshire.
1866. ‡Clayden, P. W. 13 Tavistock-square, London, W.C.
1850. ‡Cleghorn, Hugh, M.D., F.L.S. Stravithie, St. Andrews, Scotland.
1859. ‡Cleghorn, John. Wick.
1875. ‡Clegram, T. W. B. Saul Lodge, near Stonehouse, Gloucestershire.
1861. §Cleland, John, M.D., D.Sc., F.R.S., Professor of Anatomy in the University of Glasgow. 2 College, Glasgow.
1873. §Cliff, John, F.G.S. Linnburn, Ilkley, near Leeds.
1883. ‡Clift, Frederic, LL.D. Norwood, Surrey.
1861. *Clifton, R. Bellamy, M.A., F.R.S., F.R.A.S., Professor of Experimental Philosophy in the University of Oxford. Portland Lodge, Park Town, Oxford.
Clonbrock, Lord Robert. Clonbrock, Galway.
1878. §Close, Rev. Maxwell H., F.G.S. 40 Lower Baggot-street, Dublin.
1873. ‡Clough, John. Bracken Bank, Keighley, Yorkshire.
1861. *Clouston, Peter. 1 Park-terrace, Glasgow.
1883. *Clowes, Frank, D.Sc., F.C.S., Professor of Chemistry in University College, Nottingham. University College, Nottingham.
1863. *Clutterbuck, Thomas. Warkworth, Acklington.
1881. *Clutton, William James. The Mount, York.
1885. §Clyne James. Rubislaw Den South, Aberdeen.
1868. ‡Coaks, J. B. Thorpe, Norwich.
1855. *Coats, Sir Peter. Woodside, Paisley.
Cobb, Edward. Falkland House, St. Ann's, Lewes.
1884. ‡Cobb, John. Lenzie, near Glasgow.
1864. ‡Cobbold, T. Spencer, M.D., F.R.S., F.L.S., Professor of Botany and Helminthology in the Royal Veterinary College, London. 74 Portsdown-road, Maida Hill, London, W.
1864. *Cochrane, James Henry. Elm Lodge, Prestbury, Cheltenham.
1884. *Cockburn-Hood, J. J. Walton Hall, Kelso, N.B.
1883. §Cockshott, J. J. 74 Belmont-street, Southport.
1861. *Coe, Rev. Charles C., F.R.G.S. Fairfield, Heaton, Bolton

Year of Election.

1881. §Coffin, Walter Harris, F.C.S. 94 Cornwall-gardens, South Kensington, London, S.W.
1865. ‡Coghill, H. Newcastle-under-Lyme.
1884. *Cohen, B. L. 30 Hyde Park-gardens, London, W.
1876. ‡Colbourn, E. Rushton. 5 Marchmont-terrace, Hillhead, Glasgow.
1853. ‡Colchester, William, F.G.S. Springfield House, Ipswich.
1868. ‡Colchester, W. P. Bassingbourn, Royston.
1879. ‡Cole, Skelton. 387 Glossop-road, Sheffield.
1876. ‡Colebrooke, Sir T. E., Bart., M.P., F.R.G.S. 14 South-street, Park-lane, London, W.; and Abington House, Abington, N.B.
1860. ‡Coleman, J. J., F.C.S. Ardarrode, Bearsden, near Glasgow.
1878. ‡Coles, John, Curator of the Map Collection R.G.S. 1 Savile-row, London, W.
1854. *Colfox, William, B.A. Westmead, Bridport, Dorsetshire.
1857. ‡Colles, William, M.D. 21 Stephen's-green, Dublin.
1869. ‡Collier, W. F. Woodtown, Horrabridge, South Devon.
1854. ‡Collingwood, Cuthbert, M.A., M.B., F.L.S. 2 Gipsy Hill-villas, Upper Norwood, Surrey, S.E.
1861. *Collingwood, J. Frederick, F.G.S. New Athenæum Club, 3 Pall Mall East, London, S.W.
1865. *Collins, James Tertius. Churchfield, Edgbaston, Birmingham.
1876. ‡Collins, J. H., F.G.S. 64 Bickerton-road, London, N.
1876. ‡Collins, Sir William. 3 Park-terrace East, Glasgow.
1884. §Collins, William J., M.D., B.Sc. Albert-terrace, Regent's Park, London, N.W.
1883. ‡Collis, W. Elliott. 3 Lincoln's-Inn-fields, London, W.C.
1868. *Colman, J. J., M.P. Carrow House, Norwich; and 108 Cannon-street, London, E.C.
1882. ‡Colmer, Joseph G. Office of the High Commissioner for Canada, 9 Victoria-chambers, London, S.W.
1884. ‡Colomb, Capt. J. C. R., F.R.G.S. Dromquinna, Kenmare, Kerry, Ireland; and Junior United Service Club, London, S.W.
1870. ‡Coltart, Robert. The Hollies, Aigburth-road, Liverpool.
1884. §Common, A. A., F.R.S., F.R.A.S. 63 Eaton-rise, Ealing, Middlesex, W.
1846. *Compton, Lord William, M.P. 145 Piccadilly, London, W.
1884. §Conklin, Dr. William A. Central Park, New York, U.S.A.
1852. ‡Connal, Sir Michael. 16 Lynedock-terrace, Glasgow.
1871. *Connor, Charles C. Notting Hill House, Belfast.
1881. ‡Conroy, Sir John, Bart. Arborfield, Reading, Berks.
1876. ‡Cook, James. 162 North-street, Glasgow.
1882. ‡Cooke, Major-General A. C., R.E., C.B., F.R.G.S., Director-General of the Ordnance Survey. Southampton.
1876. *Cooke, Conrad W. 2 Victoria-mansions, Victoria-street, London, S.W.
1881. ‡Cooke, F. Bishophill, York.
1868. ‡Cooke, Rev. George H. Wanstead Vicarage, near Norwich.
Cooke, J. B. Cavendish-road, Birkenhead.
1868. ‡Cooke, M. C., M.A. 2 Grosvenor-villas, Upper Holloway, London, N.
1884. ‡Cooke, R. P. Brockville, Ontario, Canada.
1878. ‡Cooke, Samuel, M.A., F.G.S. Poona, Bombay.
1881. ‡Cooke, Thomas. Bishophill, York.
1859. *Cooke, His Honour Judge, M.A., F.S.A. 42 Wimpole-street, London, W.; and Rainthorpe Hall, Long Stratton.
1883. §Cooke-Taylor, R. Whateley. Frenchwood House, Preston.
1883. ‡Cooke-Taylor, Mrs. Frenchwood House, Preston.
1865. ‡Cooksey, Joseph. West Bromwich, Birmingham.

Year of Election.

1869. ‡Cooling, Edwin, F.R.G.S. Mile Ash, Derby.
1883. ‡*Coomer, John. 53 Albert-road, Southport.*
1884. ‡Coon, John S. 604 Main-street, Cambridge Pt., Massachusetts, U.S.A.
1883. ‡Cooper, George B. 67 Great Russell-street, London, W.C.
1850. ‡Cooper, Sir Henry, M.D. 7 Charlotte-street, Hull.
1838. Cooper, James. 58 Pembridge-villas, Bayswater, London, W.
1884. §Cooper, Mrs. M. A. West Tower, Marple, Cheshire.
1879. §Cooper, Thomas. Rose Hill, Rotherham, Yorkshire.
1846. ‡Cooper, William White, F.R.C.S. 19 Berkeley-square, London, W.
1868. ‡Cooper, W. J. The Old Palace, Richmond, Surrey.
1884. ‡Cope, E. D. Philadelphia, U.S.A.
1878. ‡Cope, Rev. S. W. Bramley, Leeds.
1871. ‡Copeland, Ralph, Ph.D., F.R.A.S. Dun Echt, Aberdeen.
1868. ‡Copeman, Edward, M.D. Upper King-street, Norwich.
1885. §Copland, W., M.A. Tortorston, Peterhead, N.B.
1881. ‡Copperthwaite, H. Holgate Villa, Holgate-lane, York.
1863. ‡Coppin, John. North Shields.
1842. Corbett, Edward. Grange Avenue, Levenshulme, Manchester.
1881. §Cordeaux, John. Great Cotes, Ulceby, Lincolnshire.
1883. *Core, Thomas H. Fallowfield, Manchester.
1870. *Corfield, W. H., M.A., M.D., F.C.S., F.G.S., Professor of Hygiène and Public Health in University College. 10 Bolton-row, Mayfair, London, W.
Cory, Rev. Robert, B.D., F.C.P.S. Stanground, Peterborough.
1885. §Corry, John. Rosenheim, Parkhill-road, Croydon.
1883. ‡Costelloe, B. F. C., M.A., B.Sc. 33 Chancery-lane, London, W.C.
Cottam, George. 2 Winsley-street, London, W.
1857. ‡Cottam, Samuel. Brazenose-street, Manchester.
1855. ‡Cotterill, Rev. Henry, D.D., Bishop of Edinburgh. Edinburgh.
1874. *Cotterill, J. H., M.A., F.R.S., Professor of Applied Mechanics. Royal Naval College, Greenwich, S.E.
1864. ‡Cotton, General Frederick C., R.E., C.S.I. 13 Longridge-road, Earl's Court-road, London, S.W.
1869. ‡Cotton, William. Pennsylvania, Exeter.
1879. ‡Cottrill, Gilbert I. Shepton Mallett, Somerset.
1876. ‡Couper, James. City Glass Works, Glasgow.
1876. ‡Couper, James, jun. City Glass Works, Glasgow.
1874. ‡Courtauld, John M. Bocking Bridge, Braintree, Essex.
1834. ‡Cowan, Charles. 38 West Register-street, Edinburgh.
1876. ‡Cowan, J. B., M.D. Helensburgh, N.B.
Cowan, John. Valleyfield, Pennycuick, Edinburgh.
1863. ‡Cowan, John A. Blaydon Burn, Durham.
1863. ‡Cowan, Joseph, jun. Blaydon, Durham.
1872. *Cowan, Thomas William, F.G.S. Comptons Lea, Horsham.
Cowie, The Very Rev. Benjamin Morgan, M.A., D.D., Dean of Exeter. The Deanery, Exeter.
1871. ‡Cowper, C. E. 3 Great George-street, Westminster, S.W.
1860. ‡Cowper, Edward Alfred, M.Inst.C.E. 6 Great George-street, Westminster, S.W.
1867. *Cox, Edward. Lyndhurst, Dundee.
1867. *Cox, George Addison. Beechwood, Dundee.
1870. *Cox, James. 8 Falkner-square, Liverpool.
1882. ‡Cox, Thomas A., District Engineer of the S., P., and D. Railway. Lahore, Punjab. Care of Messrs. Grindlay & Co., Parliament-street, London, S.W.

Year of Election.

1867. *Cox, Thomas Hunter. Duncarse, Dundee.
1867. ‡Cox, William. Foggley, Lochee, by Dundee.
1883. §Crabtree, William, C.E. Manchester-road, Southport.
1884. §Craigie, Major P. G., F.S.S. 6 Lyndhurst-road, Hampstead, London, N.W.
1876. ‡Cramb, John. Larch Villa, Helensburgh, N.B.
1879. §Crampton, Thomas Russell, M.Inst.C.E. 19 Ashley-place, London, S.W.
1858. ‡Cranage, Edward, Ph.D. The Old Hall, Wellington, Shropshire.
1884. ‡Crathern, James. Sherbrooke-street, Montreal, Canada.
1876. ‡Crawford, Chalmond. Ridemon, Crosscar.
1871. *Crawford, William Caldwell, M.A. 1 Lockharton-gardens, Slateford, Edinburgh.
1871. *Crawford and Balcarres, The Right Hon. the Earl of, LL.D., F.R.S., F.R.A.S. The Observatory, Dun Echt, Aberdeen.
1883. *Crawshaw, Edward. 25 Tollington-park, London, N.
1870. *Crawshay, Mrs. Robert. Cathedine, Bwlch, Breconshire.
1885. §Creak, Staff Commander E. W., R.N., F.R.S. Richmond Lodge, Blackheath, London, S.E.
1879. ‡Creswick, Nathaniel. Handsworth Grange, near Sheffield.
1876. *Crewdson, Rev. George. St. George's Vicarage, Kendal.
1880. *Crisp, Frank, B.A., LL.B., F.L.S. 5 Lansdowne-road, Notting Hill, London, W.
1878. ‡Croke, John O'Byrne, M.A. The French College, Blackrock, Dublin.
1859. ‡Croll, A. A. 10 Coleman-street, London, E.C.
1857. ‡Crolly, Rev. George. Maynooth College, Ireland.
1885. §Crombie, Charles W. 41 Carden-place, Aberdeen.
1885. §Crombie, John. Balgownie Lodge, Aberdeen.
1885. §Crombie, John, jun. Daveston, Aberdeen.
1885. §Crombie, J. W., M.A. Balgownie Lodge, Aberdeen.
1885. §Crombie, Theodore. 18 Albyn-place, Aberdeen.
1870. ‡Crookes, Joseph. Marlborough House, Brook Green, Hammersmith, London, W.
1865. §Crookes, William, F.R.S., F.C.S. 7 Kensington Park-gardens, London, W.
1879. ‡Crookes, Mrs. 7 Kensington Park-gardens, London, W.
1855. ‡Cropper, Rev. John. Wareham, Dorsetshire.
1870. ‡Crosfield, C. J. 16 Alexandra-drive, Prince's Park, Liverpool.
1870. *Crosfield, William, jun. 16 Alexandra-drive, Prince's Park, Liverpool.
1870. ‡Crosfield, William, sen. Annesley, Aigburth, Liverpool.
1861. ‡Cross, Rev. John Edward, M.A. Appleby Vicarage, near Brigg.
1883. ‡Cross, Rev. Prebendary, LL.B. Part-street, Southport.
1868. ‡Crosse, Thomas William. St. Giles's-street, Norwich.
1867. §Crosskey, Rev. H. W., LL.D., F.G.S. 117 Gough-road, Birmingham.
1853. ‡Crosskill, William, C.E. Beverley, Yorkshire.
1870. *Crossley, Edward, F.R.A.S. Bemerside, Halifax.
1871. ‡Crossley, Herbert. Broomfield, Halifax.
1866. *Crossley, Louis J., F.M.S. Moorside Observatory, near Halifax.
1883. §Crowder, Robert. Stannix, Carlisle.
1882. §Crowley, Frederick. Ashdell, Alton, Hampshire.
1861. §Crowley, Henry. Trafalgar-road, Birkdale Park, Southport.
1883. §Crowther, Elon. Cambridge-road, Huddersfield.
1863. ‡Cruddas, George. Elswick Engine Works, Newcastle-on-Tyne.
1885. §Cruickshank, Alexander, LL.D. 20 Rose-street, Aberdeen.
1860. ‡Cruickshank, John. Aberdeen.
1859. ‡Cruickshank, Provost. Macduff, Aberdeen.
1873. ‡Crust, Walter. Hall-street, Spalding.

Year of Election.

1883. *Cryer, Major J. H. The Grove, Manchester-road, Southport.
Culley, Robert. Bank of Ireland, Dublin.
1883. *Culverwell, Edward P. 40 Trinity College, Dublin.
1878. ‡Culverwell, Joseph Pope. St. Lawrence Lodge, Sutton, Dublin.
1883. ‡Culverwell, T. J. H. Litfield House, Clifton, Bristol.
1859. ‡Cumming, Sir A. P. Gordon, Bart. Altyre.
1874. ‡Cumming, Professor. 33 Wellington-place, Belfast.
1861. *Cunliffe, Edward Thomas. The Parsonage, Handforth, Manchester.
1861. *Cunliffe, Peter Gibson. Dunedin, Handforth, Manchester.
1882. *Cunningham, Major Allan, R.E., A.I.C.E. 9 Campden Hill-road, Kensington, London, W.
1877. *Cunningham, D. J., M.D., Professor of Anatomy in Trinity College, Dublin.
1852. ‡Cunningham, John. Macedon, near Belfast.
1885. §Cunningham, J. T. Scottish Marine Station, Granton, Edinburgh.
1869. ‡CUNNINGHAM, ROBERT O., M.D., F.L.S., Professor of Natural History in Queen's College, Belfast.
1883. *Cunningham, Rev. William, B.D., D.Sc. Trinity College, Cambridge.
1850. ‡Cunningham, Rev. William Bruce. Prestonpans, Scotland.
1881. ‡Curley, T., C.E., F.G.S. Hereford.
1885. §Curphey, William S. 268 Renfrew-street, Glasgow.
1884. §Currier, John McNab. Castleton, Vermont, U.S.A.
1867. *Cursetjee, Manockjee, F.R.G.S., Judge of Bombay. Villa-Byculla, Bombay.
1857. ‡CURTIS, ARTHUR HILL, LL.D. 1 Hume-street, Dublin.
1878. ‡Curtis, William. Caramore, Sutton, Co. Dublin.
1884. ‡Cushing, Frank Hamilton. Washington, U.S.A.
1883. ‡Cushing, Mrs. M. Croydon, Surrey.
1881. §Cushing, Thomas, F.R.A.S. India Store Depôt, Belvedere-road, Lambeth, London, S.W.

1854. ‡Daglish, Robert, M.Inst.C.E. Orrell Cottage, near Wigan.
1883. ‡Dähne, F. W., Consul of the German Empire. 18 Somerset-place, Swansea.
1863. ‡Dale, J. B. South Shields.
1865. ‡Dale, Rev. R. W. 12 Calthorpe-street, Birmingham.
1867. ‡Dalgleish, W. Dundee.
1870. ‡DALLINGER, Rev. W. H., LL.D., F.R.S., F.L.S. Wesley College, Glossop-road, Sheffield.
Dalmahoy, James, F.R.S.E. 9 Forres-street, Edinburgh.
Dalton, Edward, LL.D., F.S.A. Dunkirk House, Nailsworth.
*Dalton, Rev. J. E., B.D. Seagrave, Loughborough.
1862. ‡DANBY, T. W., M.A., F.G.S. 1 Westbourne-terrace-road, London, W.
1859. ‡Dancer, J. B., F.R.A.S. Old Manor House, Ardwick, Manchester.
1876. ‡Dansken, John. 4 Eldon-terrace, Partickhill, Glasgow.
1849. *Danson, Joseph, F.C.S. Montreal, Canada.
1861. *DARBISHIRE, ROBERT DUKINFIELD, B.A., F.G.S. 26 George-street, Manchester.
1883. ‡Darbishire, S. D., M.D. 60 High-street, Oxford.
1876. ‡Darling, G. Erskine. 247 West George-street, Glasgow.
1884. ‡Darling, Thomas. 99 Drummond-street, Montreal, Canada.
1882. ‡DARWIN, FRANCIS, M.A., F.R.S., F.L.S. Huntingdon-road, Cambridge.
1881. *DARWIN, GEORGE HOWARD, M.A., LL.D., F.R.S., F.R.A.S., Plumian Professor of Astronomy and Experimental Philosophy in the University of Cambridge. Newnham Grange, Cambridge.

Year of Election.

1878. *Darwin, Horace. The Orchard, Huntingdon-road, Cambridge.
1882. §Darwin, W. E., F.G.S. Bassett, Southampton.
1848. ‡DaSilva, Johnson. Burntwood, Wandsworth Common, London, S.W.
1878. ‡D'Aulmay, G. 22 Upper Leeson-street, Dublin.
1872. ‡Davenport, John T. 64 Marine Parade, Brighton.
1880. §Davey, Henry, M.Inst.C.E. Rupert Lodge, Grove-road, Headingley, Leeds.
1884. ‡David, A. J., B.A., LL.B. 4 Harcourt-buildings, Temple, London, E.C.
1870. ‡Davidson, Alexander, M.D. 2 Gambier-terrace, Liverpool.
1885. §Davidson, Charles B. Roundhay, Fonthill-road, Aberdeen.
1871. ‡*Davidson, James. Newbattle, Dalkeith, N.B.*
1875. ‡Davies, David. 2 Queen's-square, Bristol.
1870. ‡Davies, Edward, F.C.S. 88 Seel-street, Liverpool.
1842. Davies-Colley, Dr. Thomas. Newton, near Chester.
1873. *Davis, Alfred. Parliament Mansions, London, S.W.
1870. *Davis, A. S. 6 Paragon-buildings, Cheltenham.
1864. ‡Davis, Charles E., F.S.A. 55 Pulteney-street, Bath.
Davis, Rev. David, B.A. Lancaster.
1881. ‡Davis, George E. The Willows, Fallowfield, Manchester.
1882. §Davis, Henry C. Berry Pomeroy, Springfield-road, Brighton.
1873. *Davis, James W., F.G.S., F.S.A. Chevinedge, near Halifax.
1856. *Davis, Sir John Francis, Bart., K.C.B., F.R.S., F.R.G.S. Hollywood, near Compton, Bristol.
1883. ‡Davis, Joseph, J.P. Park-road, Southport.
1883. ‡Davis, Robert Frederick, M.A. Earlsfield, Wandsworth Common, London, S.W.
1885. *Davis, Rudolf. Castle Howell School, Lancaster.
1882. ‡*Davis, W. H. Gloucester Lodge, Portswood, Southampton.*
1864. *Davison, Richard. Beverley-road, Great Driffield, Yorkshire.
1857. ‡Davy, Edmund W., M.D. Kimmage Lodge, Roundtown, near Dublin.
1869. ‡Daw, John. Mount Radford, Exeter.
1869. ‡Daw, R. M. Bedford-circus, Exeter.
1860. *Dawes, John T., F.G.S. Blaen-y-Roe, St. Asaph, North Wales.
1864. ‡Dawkins, W. Boyd, M.A., F.R.S., F.G.S., F.S.A., Professor of Geology and Palæontology in the Victoria University, Owens College, Manchester. Woodhurst, Fallowfield, Manchester.
1885. *Dawson, Captain H. P., R.A. Junior United Service Club, Pall Mall, London, S.W.
Dawson, John. Barley House, Exeter.
1884. ‡Dawson, Samuel. 258 University-street, Montreal, Canada.
1855. ‡Dawson, Sir William, C.M.G., M.A., LL.D., F.R.S., F.G.S., Principal of M'Gill College. (President Elect.) M'Gill College, Montreal, Canada.
1859. *Dawson, Captain William G. Plumstead Common, Kent.
1879. ‡Day, Francis. Kenilworth House, Cheltenham.
1871. ‡Day, St. John Vincent, M.Inst.C.E., F.R.S.E. 166 Buchanan-street, Glasgow.
1870. *Deacon, G. F., M.Inst.C.E. Rock Ferry, Liverpool.
1861. ‡Deacon, Henry. Appleton House, near Warrington.
1861. ‡Dean, Henry. Colne, Lancashire.
1870. *Deane, Rev. George, B.A., D.Sc., F.G.S. Spring Hill College, Moseley, near Birmingham.
1884. *Debenham, Frank, F.S.S. 26 Upper Hamilton-terrace, London, N.W.
1866. ‡Debus, Heinrich, Ph.D., F.R.S., F.C.S., Lecturer on Chemistry at Guy's Hospital, London, S.E.
1884. §Deck, Arthur, F.C.S. 9 King's-parade, Cambridge.

Year of
Election.

1882. *De Chaumont, François, M.D., F.R.S., Professor of Hygiène in the Royal Victoria Hospital, Netley.
1878. ‡Delany, Rev. William. St. Stanislaus College, Tullamore.
1854. *De La Rue, Warren, M.A., D.C.L., Ph.D., F.R.S., F.C.S., F.R.A.S. 73 Portland-place, London, W.
1879. ‡De la Sala, Colonel. Sevilla House, Navarino-road, London, N.W.
1884. *De Laune, C. DeL. F. Sharsted Court, Sittingbourne.
1870. ‡De Meschin, Thomas, M.A., LL.D. 8 New-square, Lincoln's Inn, London, W.C.
Denchar, John. Morningside, Edinburgh.
1873. ‡Denham, Thomas. Huddersfield.
1884. ‡Denman, Thomas W. Lamb's-buildings, Temple, London, E.C.
1875. ‡Denny, William. Seven Ship-yard, Dumbarton.
Dent, William Yerbury. Royal Arsenal, Woolwich.
1870. *Denton, J. Bailey. 22 Whitehall-place, London, S.W.
1874. §De Rance, Charles E., F.G.S. 28 Jermyn-street, London, S.W.
1856. *Derby, The Right Hon. the Earl of, K.G., M.A., LL.D., F.R.S., F.R.G.S. 23 St. James's-square, London, S.W.; and Knowsley, near Liverpool.
1874. *Derham, Walter, M.A., LL.M., F.G.S. Henleaze Park, Westbury-on-Trym, Bristol.
1878. ‡De Rinzy, James Harward. Khelat Survey, Sukkur, India.
1868. ‡Dessé, Etheldred, M.B., F.R.C.S. 43 Kensington Gardens-square, Bayswater, London, W.
De Tabley, George, Lord, F.Z.S. Tabley House, Knutsford, Cheshire.
1869. ‡Devon, The Right Hon. the Earl of, D.C.L. Powderham Castle, near Exeter.
*Devonshire, His Grace the Duke of, K.G., M.A., LL.D., F.R.S., F.G.S., F.R.G.S., Chancellor of the University of Cambridge. Devonshire House, Piccadilly, London, W.; and Chatsworth, Derbyshire.
1868. ‡Dewar, James, M.A., F.R.S. L. & E., F.C.S., Fullerian Professor of Chemistry in the Royal Institution, London, and Jacksonian Professor of Natural Experimental Philosophy in the University of Cambridge. 1 Scroope-terrace, Cambridge.
1881. ‡Dewar, Mrs. 1 Scroope-terrace, Cambridge.
1883. ‡Dewar, James, M.D., F.R.C.S.E. Drylaw House, Davidson's Mains, Midlothian, N.B.
1884. *Dewar, William. 6 Montpellier-grove, Cheltenham.
1872. ‡Dewick, Rev. E. S., M.A., F.G.S. 2 Southwick-place, Hyde Park, London, W.
1884. §De Wolf, O. C., M.D. Chicago, U.S.A.
1873. *Dew-Smith, A. G., M.A. 7a Eaton-square, London, S.W.
1883. §Dickinson, A. P. Fair Elms, Blackburn.
1864. *Dickinson, F. H., F.G.S. Kingweston, Somerton, Taunton; and 121 St. George's-square, London, S.W.
1863. ‡Dickinson, G. T. Claremont-place, Newcastle-on-Tyne.
1867. ‡Dickson, Alexander, M.D., Professor of Botany in the University of Edinburgh. 11 Royal-circus, Edinburgh.
1884. ‡Dickson, Charles R., M.D. Wolfe Island, Ontario, Canada.
1881. ‡Dickson, Edmund. West Cliff, Preston.
1885. §Dickson, Patrick. Laurencekirk, Aberdeen.
1883. ‡Dickson, T. A. West Cliff, Preston.
1862. *Dilke, The Right Hon. Sir Charles Wentworth, Bart., M.P., F.R.G.S. 76 Sloane-street, London, S.W.
1877. §Dillon, James, M.Inst.C.E. 36 Dawson-street, Dublin.

Year of Election.

1848. ‡DILLWYN, LEWIS LLEWELYN, M.P., F.L.S., F.G.S. Parkwerne, near Swansea.
1872. ‡DINES, GEORGE. Woodside, Hersham, Walton-on-Thames.
1869. ‡Dingle, Edward. 19 King-street, Tavistock.
1876. ‡Ditchfield, Arthur. 12 Taviton-street, Gordon-square, London, W.C.
1868. ‡Dittmar, William, F.R.S. L. & E., F.C.S., Professor of Chemistry in Anderson's College, Glasgow.
1884. §Dix, John William H. Bristol.
1874. *Dixon, A. E. Dunowen, Cliftonville, Belfast.
1883. ‡Dixon, Miss E. 2 Cliff-terrace, Kendal.
1853. ‡Dixon, Edward. Wilton House, Southampton.
1879. *DIXON, HAROLD B., M.A., F.C.S. Trinity College, Oxford.
1885. §Dixon, John Henry. Inverair, Poolewe, Ross-shire, N.B.
1885. §Doak, Rev. A. 15 Queen's-road, Aberdeen.
1885. §Dobbin, Leonard. The University, Edinburgh.
1860. *Dobbs, Archibald Edward, M.A. 34 Westbourne Park, London, W.
1878. *DOBSON, G. E., M.A., M.B., F.R.S., F.L.S. Royal Victoria Hospital, Netley, Southampton.
1864. *Dobson, William. Oakwood, Bathwick Hill, Bath.
1875. *Docwra, George, jun. Grosvenor-road, Handsworth, Birmingham.
1870. *Dodd, John. 53 Cable-street, Liverpool.
1876. ‡Dodds, J. M. St. Peter's College, Cambridge.
Dolphin, John. Delves House, Berry Edge, near Gateshead.
1851. ‡Domvile, William C., F.Z.S. Thorn Hill, Bray, Dublin.
1867. ‡Don, John. The Lodge, Broughty Ferry, by Dundee.
1867. ‡Don, William G. St. Margaret's, Broughty Ferry, by Dundee.
1885. §Donaldson, James, M.A., LL.D., F.R.S.E., Regius Professor of Humanity in the University of Aberdeen. Old Aberdeen.
1882. ‡Donaldson, John. Tower House, Chiswick, Middlesex.
1869. ‡Donisthorpe, G. T. St. David's Hill, Exeter.
1877. *Donkin, Bryan, jun. May's Hill, Shortlands, Kent.
1874. ‡Donnell, Professor, M.A. 76 Stephen's-green South, Dublin.
1861. ‡Donnelly, Colonel, R.E. South Kensington Museum, London, W.
1881. ‡Dorrington, John Edward. Lypiatt Park, Stroud.
1867. ‡Dougall, Andrew Maitland, R.N. Scotscraig, Tayport, Fifeshire.
1871. ‡Dougall, John, M.D. 2 Cecil-place, Paisley-road, Glasgow.
1863. *Doughty, Charles Montagu. Care of H. M. Doughty, Esq., 5 Stone-court, Lincoln's Inn, London, W.C.
1876. *Douglas, Rev. G. C. M. 18 Royal-crescent West, Glasgow.
1877. *Douglass, Sir James N., M.Inst.C.E. Trinity House, London, E.C.
1878. ‡Douglass, William. 104 Baggot-street, Dublin.
1884. ‡Douglass, William Alexander. Freehold Loan and Savings Company, Church-street, Toronto, Canada.
1883. §Dove, Arthur. Crown Cottage, York.
1884. §Dove, Miss Frances. St. Leonard's, St. Andrews, N.B.
1884. ‡Dove, P. Edward, F.R.A.S., Sec.R.Hist.Soc. 9 Argyll-street, Regent-street, London, W.
1884. ‡Dowe, John Melnotte. 69 Seventh-avenue, New York, U.S.A.
1870. ‡Dowie, J. Muir. Java Lodge, Craigmore, Mull, N.B.
1876. ‡Dowie, Mrs. Muir. Java Lodge, Craigmore, Mull, N.B.
1884. *Dowling, D. J. Bromley, Kent.
1878. ‡Dowling, Thomas. Claireville House, Terenure, Dublin.
1882. §DOWNES, Rev. W., B.A., F.G.S. Combe Raleigh Rectory, Honiton.
1857. ‡DOWNING, S., LL.D. 4 The Hill, Monkstown, Co. Dublin.
1878. ‡Dowse, The Right Hon. Baron. 38 Mountjoy-square, Dublin.
1865. *Dowson, E. Theodore, F.R.M.S. Geldeston, near Beccles, Suffolk.

Year of Election.

1881. §Dowson, Joseph Emerson, C.E. 3 Great Queen-street, London, S.W.
1883. ‡Draper, William. De Grey House, St. Leonard's, York.
1868. ‡DRESSER, HENRY E., F.Z.S. 6 Tenterden-street, Hanover-square, London, W.
1873. §DREW, FREDERIC, F.G.S., F.R.G.S. Eton College, Windsor.
1879. ‡*Drew, Joseph, M.B. Foxgrove-road, Beckenham, Kent.*
1879. ‡Drew, Samuel, M.D., D.Sc., F.R.S.E. 10 Laura-place, Bath.
1870. §Drysdale, J. J., M.D. 36A Rodney-street, Liverpool.
1884. ‡Du Bois, Henri. 39 Bentick-street, Glasgow.
1856. *DUCIE, The Right. Hon. HENRY JOHN REYNOLDS MORETON, Earl of, F.R.S., F.G.S. 16 Portman-square, London, W.; and Tortworth Court, Wotton-under-Edge.
1883. ‡*Duck, A. E. Southport.*
1870. ‡Duckworth, Henry, F.L.S., F.G.S. Holme House, Columbia-road, Oxton, Birkenhead.
1867. *DUFF, The Right Hon. MOUNTSTUART ELPHINSTONE GRANT-, F.R.S., F.R.G.S., Governor of Madras. Care of W. Hunter, Esq., 14 Adelphi-court, Union-street, Aberdeen.
1852. ‡Dufferin and Clandeboye, The Right Hon. the Earl of, K.P., G.C.B., LL.D., F.R.S., F.R.G.S., Governor-General of India. Clandeboye, near Belfast, Ireland.
1877. ‡Duffey, George F., M.D. 30 Fitzwilliam-place, Dublin.
1875. ‡Duffin, W. E. L'Estrange. Waterford.
1884. §Dugdale, James H. 9 Hyde Park-gardens, London, W.
1883. §Duke, Frederic. Conservative Club, Hastings.
1859. *Duncan, Alexander. 7 Prince's-gate, London, S.W.
1866. *Duncan, James. 71 Cromwell-road, South Kensington, London, S.W.
1871. ‡Duncan, James Matthew, M.D. 30 Charlotte-square, Edinburgh.
Duncan, J. F., M.D. 8 Upper Merrion-street, Dublin.
1867. ‡DUNCAN, PETER MARTIN, M.B., F.R.S., F.G.S., Professor of Geology in King's College, London. 6 Grosvenor-road, Gunnersbury, London, W.
1880. ‡Duncan, William S. 22 Delamere-terrace, Bayswater, London, W.
1881. §Duncombe, The Hon. Cecil. Nawton Grange, York.
1881. ‡Dunhill, Charles H. Gray's-court, York.
1853. *Dunlop, William Henry. Annanhill, Kilmarnock, Ayrshire.
1865. ‡Dunn, David. Annet House, Skelmorlie, by Greenock, N.B.
1876. *Dunn, James. 64 Robertson-street, Glasgow.
1882. §Dunn, J. T., M.Sc., F.C.S. High School for Boys, Gateshead-on-Tyne.
1883. §Dunn, Mrs. 115 Scotswood-road, Newcastle-on-Tyne.
1876. ‡Dunnachie, James. 2 West Regent-street, Glasgow.
1878. ‡Dunne, D. B., M.A., Ph.D., Professor of Logic in the Catholic University of Ireland. 4 Clanwilliam-place, Dublin.
1884. ‡Dunnington, F. P. University of Virginia, Virginia, U.S.A.
1859. ‡Duns, Rev. John, D.D., F.R.S.E. New College, Edinburgh.
1885. *Dunstan, Wyndham, F.C.S., Professor of Chemistry to the Pharmaceutical Society of Great Britain. 17 Bloomsbury-square, London, W.C.
1866. ‡Duprey, Perry. Woodberry Down, Stoke Newington, London, N.
1869. ‡D'Urban, W. S. M., F.L.S. 4 Queen-terrace, Mount Radford, Exeter.
1860. ‡DURHAM, ARTHUR EDWARD, F.R.C.S., F.L.S., Demonstrator of Anatomy, Guy's Hospital. 82 Brook-street, Grosvenor-square, London, W.
1884. ‡Dyck, Professor Walter. The University, Munich.
1885. *Dyer, Henry, M.A. 8 Highburgh-terrace, Dowanhill, Glasgow.
Dykes, Robert. Kilmorie, Torquay, Devon.
1869. *Dymond, Edward E. Oaklands, Aspley Guise, Woburn.

Year of Election.

1868. ‡Eade, Peter, M.D. Upper St. Giles's-street, Norwich.
1884. §Eads, Captain James B. 34 Nassau-street, New York, U.S.A.
1861. ‡Eadson, Richard. 13 Hyde-road, Manchester.
1883. ‡Eagar, Rev. Thomas. The Rectory, Ashton-under-Lyne.
1877. ‡Earle, Ven. Archdeacon, M.A. West Alvington, Devon.
1833. *EARNSHAW, Rev. SAMUEL, M.A. 14 Beechhill-road, Sheffield.
1874. ‡Eason, Charles. 30 Kenilworth-square, Rathgar, Dublin.
1883. ‡*Eastham, Silas. 50 Leyland-road, Southport.*
1871. *EASTON, EDWARD, M.Inst.C.E., F.G.S. 11 Delahay-street, Westminster, S.W.
1863. ‡Easton, James. Nest House, near Gateshead, Durham.
1876. ‡Easton, John. Durie House, Abercromby-street, Helensburgh, N.B.
1883. §Eastwood, Miss. Littleover Grange, Derby.
1870. ‡Eaton, Richard. 1 Stafford-street, Derby.
Ebden, Rev. James Collett, M.A., F.R.A.S. Great Stukeley Vicarage, Huntingdonshire.
1884. ‡Eckersley, W. T. Standish Hall, Wigan, Lancashire.
1861. ‡Ecroyd, William Farrer. Spring Cottage, near Burnley.
1858. *Eddison, Francis. Syward Lodge, Dorchester.
1870. *Eddison, John Edwin, M.D., M.R.C.S. 29 Park-square, Leeds.
*Eddy, James Ray, F.G.S. Carleton Grange, Skipton.
Eden, Thomas. Talbot-road, Oxton.
1884. *Edgell, R. Arnold, B.A., F.C.S. Ashburnham House, Little Dean's-yard, Westminster, S.W.
1859. ‡Edmond, James. Cardens Haugh, Aberdeen.
1870. *Edmonds, F. B. 72 Portsdown-road, London, W.
1883. ‡Edmonds, William. Wiscombe Park, Honiton, Devon.
1884. *Edmunds, James, M.D. 8 Grafton-street, Piccadilly, London, W.
1883. §Edmunds, Lewis, D.Sc., LL.B. 8 Grafton-street, Piccadilly, London, W.
1867. *Edward, Allan. Farington Hall, Dundee.
1867. ‡Edward, Charles. Chambers, 8 Bank-street, Dundee.
1855. *EDWARDS, Professor J. BAKER, Ph.D., D.C.L. Montreal, Canada.
1884. §Edwards, W. F. Niles, Michigan, U.S.A.
1876. ‡Elder, Mrs. 6 Claremont-terrace, Glasgow.
1885. *Elgar, Francis, LL.D., F.R.S.E., Professor of Naval Architecture and Marine Engineering in the University of Glasgow. 17 University Gardens, Glasgow.
1868. ‡Elger, Thomas Gwyn Empy, F.R.A.S. Manor Cottage, Kempston, Bedford.
1863. ‡Ellenberger, J. L. Worksop.
1885. §Ellingham, Frank. Thorpe St. Andrew, Norwich.
1883. ‡Ellington, Edward Bayzand, M.Inst.C.E. Palace-chambers, Bridge-street, Westminster, S.W.
1880. *Elliot, Colonel Charles, C.B. Hazelbank, Murrayfield, Midlothian, N.B.
1861. *ELLIOT, Sir WALTER, K.C.S.I., LL.D., F.R.S., F.L.S. Wolfelee, Hawick, N.B.
1864. ‡Elliott, E. B. Washington, U.S.A.
1883. *ELLIOTT, EDWIN BAILEY, M.A. Queen's College, Oxford.
1872. ‡Elliott, Rev. E. B. 11 Sussex-square, Kemp Town, Brighton.
Elliott, John Fogg. Elvet Hill, Durham.
1879. §Elliott, Joseph W. Post Office, Bury, Lancashire.
1864. *ELLIS, ALEXANDER JOHN, B.A., F.R.S., F.S.A. 25 Argyll-road, Kensington, London, W.
1877. ‡Ellis, Arthur Devonshire. School of Mines, Jermyn-street, London, S.W.; and Thurnscoe Hall, Rotherham, Yorkshire.

Year of Election.

1875. *Ellis, H. D. 67 Ladbroke Grove-road, Notting Hill, London, W.
1883. ‡Ellis, John. 17 Church-street, Southport.
1880. *ELLIS, JOHN HENRY. New Close, Cambridge-road, Southport.
1864. *Ellis, Joseph. Hampton Lodge, Brighton.
1864. ‡Ellis, J. Walter. High House, Thornwaite, Ripley, Yorkshire.
Ellis, Rev. Robert, A.M. The Institute, St. Saviour's Gate, York.
1884. ‡Ellis, W. Hodgson. Toronto, Canada.
1869. ‡ELLIS, WILLIAM HORTON. Hartwell House, Exeter.
Ellman, Rev. E. B. Berwick Rectory, near Lewes, Sussex.
1862. ‡Elphinstone, H. W., M.A., F.L.S. 2 Stone-buildings, Lincoln's Inn, London, W.C.
1883. ‡Elwes, George Robert. Bossington, Bournemouth.
1870. *ELY, The Right Rev. Lord ALWYNE COMPTON, D.D., Lord Bishop of. The Palace, Ely, Cambridgeshire.
1863. ‡Embleton, Dennis, M.D. Northumberland-street, Newcastle-on-Tyne.
1884. ‡Emery, Albert H. Stamford, Connecticut, U.S.A.
1863. ‡Emery, The Ven. Archdeacon, B.D. Ely, Cambridgeshire.
1858. ‡Empson, Christopher. Bramhope Hall, Leeds.
1866. ‡Enfield, Richard. Low Pavement, Nottingham.
1866. ‡Enfield, William. Low Pavement, Nottingham.
1884. ‡England, Luther M. Knowlton, Quebec, Canada.
1853. ‡English, Edgar Wilkins. Yorkshire Banking Company, Lowgate, Hull.
1869. ‡English, J. T. Wayfield House, Stratford-on-Avon.
ENNISKILLEN, The Right Hon. WILLIAM WILLOUGHBY, Earl of, LL.D., D.C.L., F.R.S., F.G.S., M.R.I.A. 65 Eaton-place, London, S.W.; and Florence Court, Fermanagh, Ireland.
1883. ‡Entwistle, James P. Beachfield, 2 Westclyffe-road, Southport.
1869. *Enys, John Davis. Care of F. G. Enys, Esq., Enys, Penryn, Cornwall.
1844. ‡Erichsen, John Eric, LL.D., F.R.S., F.R.C.S., Professor of Surgery in University College, London. 6 Cavendish-place, London, W.
1864. *Eskrigge, R. A., F.G.S. 18 Hackins-hey, Liverpool.
1885. §Esselmont, Peter. 34 Albyn-place, Aberdeen.
1862. *ESSON, WILLIAM, M.A., F.R.S., F.C.S., F.R.A.S. Merton College; and 13 Bradmore-road, Oxford.
1878. ‡Estcourt, Charles, F.C.S. 8 St. James's-square, John Dalton-street, Manchester.
Estcourt, Rev. W. J. B. Long Newton, Tetbury.
1869. ‡ETHERIDGE, ROBERT, F.R.S. L. & E., F.G.S., Assistant Keeper (Geological and Palæontological Department) Natural History Museum (British Museum). 14 Carlyle-square, London, S.W.
1883. §Eunson, Henry J. 20 St. Giles-street, Northampton.
1881. ‡Evans, Alfred. Exeter College, Oxford.
1870. *Evans, Arthur John, F.S.A. Nash Mills, Hemel Hempstead.
1865. *EVANS, Rev. CHARLES, M.A. The Rectory, Solihull, Birmingham.
1884. §Evans, Horace L. Moreton House, Tyndall Park, Bristol.
1869. *Evans, H. Saville W. Wimbledon Park House, Wimbledon, Surrey.
1861. *EVANS, JOHN, D.C.L., LL.D., Treas.R.S., F.S.A., F.G.S. 65 Old Bailey, London, E.C.; and Nash Mills, Hemel Hempstead.
1883. §Evans, J. C. Nevill-street, Southport.
1883. §Evans, Mrs. J. C. Nevill-street, Southport.
1881. §Evans, Lewis. Llanfyrnach R.S.O., Pembrokeshire.
1876. ‡Evans, Mortimer, M.Inst.C.E. 97 West Regent-street, Glasgow.

Year of Election.

1885. *Evans, Percy Bagnall. The Spring, Kenilworth.
1865. ‡EVANS, SEBASTIAN, M.A., LL.D. Heathfield, Alleyne Park, Lower Norwood, Surrey, S.E.
1875. ‡Evans, Sparke. 3 Apsley-road, Clifton, Bristol.
1866. ‡Evans, Thomas, F.G.S. Belper, Derbyshire.
1865. *Evans, William. The Spring, Kenilworth.
1871. §Eve, H. Weston, M.A. University College, London, W.C.
1868. *EVERETT, J. D., M.A., D.C.L., F.R.S. L. & E., Professor of Natural Philosophy in Queen's College, Belfast. Lennox-vale, Belfast.
1880. ‡Everingham, Edward. St. Helen's-road, Swansea.
1863. *Everitt, George Allen, F.R.G.S. Knowle Hall, Warwickshire.
1883. ‡Eves, Miss Florence. Uxbridge.
1881. ‡EWART, J. COSSAR, M.D., Professor of Natural History in the University of Edinburgh.
1874. ‡Ewart, William, M.P. Glenmachan, Belfast.
1874. ‡Ewart, W. Quartus. Glenmachan, Belfast.
1859. *Ewing, Sir Archibald Orr, Bart., M.P. Ballikinrain Castle, Killearn, Stirlingshire.
1876. *EWING, JAMES ALFRED, B.Sc., F.R.S.E., Professor of Engineering in University College, Dundee.
1883. ‡Ewing, James L. 52 North Bridge, Edinburgh.
1871. *Exley, John T., M.A. 1 Cotham-road, Bristol.
1884. §Eyerman, John. Easton, Pennsylvania, U.S.A.
1846. *Eyre, George Edward, F.G.S., F.R.G.S. 59 Lowndes-square, London, S.W.; and Warrens, near Lyndhurst, Hants.
1882. ‡Eyre, G. E. Briscoe. Warrens, near Lyndhurst, Hants.
Eyton, Charles. Hendred House, Abingdon.

1884. ‡Fairbairn, Dr. A. M. Airedale College, Bradford, Yorkshire.
1865. *FAIRLEY, THOMAS, F.R.S.E., F.C.S. 8 Newton-grove, Leeds.
1876. ‡Fairlie, James M. Charing Cross Corner, Glasgow.
1870. ‡Fairlie, Robert, C.E. Woodlands, Clapham Common, London, S.W.
1864. ‡Falkner, F. H. Lyncombe, Bath.
1883. ‡Fallon, Rev. W. S. 1 St. Alban's-terrace, Cheltenham.
1877. §Faraday, F. J., F.L.S., F.S.S. College Chambers, 17 Brazenose-street, Manchester.
1879. *Farnworth, Ernest. Swindon, near Dudley.
1883. §Farnworth, Walter. 86 Preston New-road, Blackburn.
1883. §Farnworth, William. 86 Preston New-road, Blackburn.
1885. §Farquhar, Admiral. Carlogie, Aberdeen.
1859. ‡Farquharson, Robert F. O. Haughton, Aberdeen.
1885. §Farquharson, Mrs. R. F. O. Haughton, Aberdeen.
1866. *FARRAR, Ven. FREDERICK WILLIAM, M.A., D.D., F.R.S., Archdeacon of Westminster. St. Margaret's Rectory, Westminster, S.W.
1883. ‡Farrell, John Arthur. Moynalty, Kells, North Ireland.
1857. ‡Farrelly, Rev. Thomas. Royal College, Maynooth.
1869. *Faulding, Joseph. Ebor Villa, Godwin-road, Clive-vale, Hastings.
1883. §Faulding, Mrs. Ebor Villa, Godwin-road, Clive-vale, Hastings.
1863. ‡*Fawcus, George. Alma-place, North Shields.*
1873. *Fazakerley, Miss. Ranwell Abbey, Weston-super-Mare, Somerset.
1845. ‡Felkin, William, F.L.S. ThePark, Nottingham.
Fell, John B. Spark's Bridge, Ulverstone, Lancashire.
1864. *FELLOWS, FRANK P., F.S.A., F.S.S. 8 The Green, Hampstead, London, N.W.

Year of Election.

1852. ‡Fenton, S. Greame. 9 College-square; and Keswick, near Belfast.
1883. ‡Fenwick, E. H. 29 Harley-street, London, W.
1876. *Fergus, Andrew, M.D. 191 Bath-street, Glasgow.
1876. ‡Ferguson, Alexander A. 11 Grosvenor-terrace, Glasgow.
1883. ‡Ferguson, Mrs. A. A. 11 Grosvenor-terrace, Glasgow.
1859. ‡Ferguson, John. Cove, Nigg, Inverness.
1871. *Ferguson, John, M.A., Professor of Chemistry in the University of Glasgow.
1867. ‡Ferguson, Robert M., Ph.D., F.R.S.E. 8 Queen-street, Edinburgh.
1857. ‡Ferguson, Sir Samuel, LL.D., Q.C. 20 Great George's-street North, Dublin.
1854. ‡Ferguson, William, F.L.S., F.G.S. Kinmundy, near Mintlaw, Aberdeenshire.
1867. *Fergusson, H. B. 13 Airlie-place, Dundee.
1883. §Fernald, H. P. Alma House, Cheltenham.
1883. *Fernie John. 113 South 40th Street, Philadelphia, U.S.A.
1862. ‡FERRERS, Rev. NORMAN MACLEOD, D.D., F.R.S. Caius College Lodge, Cambridge.
1873. ‡Ferrier, David, M.A., M.D., F.R.S., Professor of Forensic Medicine in King's College. 34 Cavendish-square, London, W.
1882. §Fewings, James, B.A., B.Sc. The Grammar School, Southampton.
1875. ‡Fiddes, Walter. Clapton Villa, Tyndall's Park, Clifton, Bristol.
1868. ‡Field, Edward. Norwich.
1869. *FIELD, ROGERS, B.A., M.Inst.C.E. 4 Westminster-chambers, Westminster, S.W.
1882. §Filliter, Freeland. St. Martin's House, Wareham, Dorset.
1883. **Finch, Gerard B., M.A.* 10 *Lyndhurst-road, Hampstead, London, N.W.*
1883. ‡*Finch, Mrs. Gerard.* 10 *Lyndhurst-road, Hampstead, London, N.W.*
Finch, John. Bridge Work, Chepstow.
Finch, John, jun. Bridge Work, Chepstow.
1885. §FINDLATER, JOHN. 60 Union-street, Aberdeen.
1878. *Findlater, William, M.P. 22 Fitzwilliam-square, Dublin.
1885. §Findlay, George, M.A. 50 Victoria-street, Aberdeen.
1884. ‡Finlay, Samuel. Montreal, Canada.
1883. §Finney, John Douglass. The West Mansions, De Vere-gardens, Kensington, London, W.
1881. ‡Firth, Colonel Sir Charles. Heckmondwike.
Firth, Thomas. Northwick.
1863. *Firth, William. Burley Wood, near Leeds.
1851. *FISCHER, Professor WILLIAM L. F., M.A., LL.D., F.R.S. St. Andrews, N.B.
1858. ‡Fishbourne, Admiral E. G., R.N. 26 Hogarth-road, Earl's Court-road, London, S.W.
1884. *Fisher, L. C. Galveston, Texas, U.S.A.
1869. ‡FISHER, Rev. OSMOND, M.A., F.G.S. Harlton Rectory, near Cambridge.
1873. §Fisher, William. Maes Fron, near Welshpool, Montgomeryshire.
1879. ‡Fisher, William. Norton Grange, near Sheffield.
1875. *Fisher, W. W., M.A., F.C.S. 5 St. Margaret's-road, Oxford.
1858. ‡Fishwick, Henry. Carr-hill, Rochdale.
1885. §Fison, E. Herbert. Stoke House, Ipswich.
1871. *FISON, FREDERICK W., M.A., F.C.S. Eastmoor, Ilkley, Yorkshire.
1871. ‡FITCH, J. G., M.A., LL.D. 5 Lancaster-terrace, Regent's Park, London, N.W.

Year of Election.

1883. ‡Fitch, Rev. J. J. Ivyholme, Southport.
1868. ‡Fitch, Robert, F.G.S., F.S.A. Norwich.
1878. ‡Fitzgerald, C. E., M.D. 27 Upper Merrion-street, Dublin.
1878. §FITZGERALD, GEORGE FRANCIS, M.A., F.R.S., Professor of Natural and Experimental Philosophy. Trinity College, Dublin.
1885. *Fitzgerald, Professor Maurice, B.A. 37 Botanic-avenue, Belfast.
1857. ‡Fitzpatrick, Thomas, M.D. 31 Lower Baggot-street, Dublin.
1881. ‡Fitzsimmons, Henry, M.D. Minster-yard, York.
1865. ‡Fleetwood, D. J. 45 George-street, St. Paul's, Birmingham.
Fleetwood, Sir Peter Hesketh, Bart. Rossall Hall, Fleetwood, Lancashire.
1850. ‡Fleming, Professor Alexander, M.D. 121 Hagley-road, Birmingham.
1881. ‡Fleming, Rev. Canon James, B.D. The Residence, York.
1876. ‡Fleming, James Brown. Beaconsfield, Kelvinside, near Glasgow.
1876. ‡Fleming, Sandford. Ottawa, Canada.
1867. §FLETCHER, ALFRED E. 57 Gordon-square, London, W.C.
1870. ‡Fletcher, B. Edgington. Norwich.
1869. ‡FLETCHER, LAVINGTON E., M.Inst.C.E. Alderley Edge, Cheshire.
Fletcher, T. B. E., M.D. 7 Waterloo-street, Birmingham.
1862. ‡FLOWER, WILLIAM HENRY, LL.D., F.R.S., F.L.S., F.G.S., F.R.C.S., Director of the Natural History Department, British Museum, South Kensington, London, S.W.
1877. *Floyer, Ernest A., F.R.G.S., F.L.S. Cairo.
1881. ‡Foljambe, Cecil G. S., M.P. 2 Carlton House-terrace, Pall Mall, London, S.W.
1879. ‡Foote, Charles Newth, M.D. 3 Albion-place, Sunderland.
1879. ‡Foote, Harry D'Oyley, M.D. Rotherham, Yorkshire.
1880. ‡Foote, R. Bruce. Care of Messrs. H. S. King & Co., 65 Cornhill, London, E.C.
1873. *FORBES, GEORGE, M.A., F.R.S.E. 34 Great George-street, London, S.W.
1883. §Forbes, Henry O., F.Z.S. Rubislaw Den, Aberdeen.
1885. §Forbes, The Right Hon. Lord. Castle Forbes, Aberdeenshire.
1866. ‡Ford, William. Hartsdown Villa, Kensington Park-gardens East, London, W.
1875. *FORDHAM, H. GEORGE, F.G.S. Odsey Grange, Royston, Cambridgeshire.
*Forrest, William Hutton. 1 Pitt-terrace, Stirling.
1883. §Formby, R. Formby, near Liverpool.
1867. ‡Forster, Anthony. Finlay House, St. Leonard's-on-Sea.
1883. ‡Forsyth, A. R. University College, Liverpool.
1884. ‡Fort, George H. Lakefield, Ontario, Canada.
1854. *Fort, Richard. Read Hall, Whalley, Lancashire.
1877. ‡FORTESCUE, The Right Hon. the Earl. Castle Hill, North Devon.
1882. §Forward, Henry. 3 Burr-street, London, E.
1870. ‡Forwood, Sir William B. Hopeton House, Seaforth, Liverpool.
1875. ‡Foster, A. Le Neve. 51 Cadogan-square, London, S.W.
1865. ‡Foster, Balthazar, M.D., Professor of Medicine in Queen's College, Birmingham. 16 Temple-row, Birmingham.
1865. *FOSTER, CLEMENT LE NEVE, B.A., D.Sc., F.G.S. Llandudno.
1883. ‡Foster, Mrs. C. Le Neve. Llandudno.
1857. *FOSTER, GEORGE CAREY, B.A., F.R.S., F.C.S., Professor of Physics in University College, London. 18 Daleham-gardens, Hampstead, London, N.W.
1881. ‡Foster, J. L. Ogleforth, York.
1845. ‡Foster, John N. Sandy Place, Sandy, Bedfordshire.
1877. §Foster, Joseph B. 6 James-street, Plymouth.

Year of Election.

1859. *FOSTER, MICHAEL, M.A., M.D., Sec. R.S., F.L.S., F.C.S., Professor of Physiology in the University of Cambridge. Trinity College, and Great Shelford, near Cambridge.
1863. ‡Foster, Robert. 30 Rye-hill, Newcastle-upon-Tyne.
1866. ‡Fowler, George, M.Inst.C.E., F.G.S. Basford Hall, near Nottingham.
1868. ‡Fowler, G. G. Gunton Hall, Lowestoft, Suffolk.
1876. *Fowler, John. 4 Kelvin Bank-terrace, Glasgow.
1882. ‡FOWLER, Sir JOHN, M.Inst.C.E., F.G.S. 2 Queen Square-place, Westminster, S.W.
1870. *Fowler, Sir Robert Nicholas, Bart., M.A., M.P., F.R.G.S. 50 Cornhill, London, E.C.
1884. §Fox, Miss A. M. Penjerrick, Falmouth.
1883. *Fox, Charles. 25 St. George's-road, Tufnell Park, London, N.
1883. §Fox, Charles Douglas, M.Inst.C.E. 5 Delahay-street, Westminster, S.W.
1860. *Fox, Rev. Edward, M.A. Upper Heyford, Banbury.
1883. ‡Fox, Howard, United States Consul. Falmouth.
1876. *Fox, Joseph Hayland. The Cleve, Wellington, Somerset.
1860. ‡Fox, Joseph John. Lordship-terrace, Stoke Newington, London, N.
1876. ‡Fox, St. G. Lane. 9 Sussex-place, London, S.W.
1881. *FOXWELL, HERBERT S., M.A., Professor of Political Economy in University College, London. St. John's College, Cambridge.
1866. *Francis, G. B. Inglesby House, Stoke Newington-green, London, N.
1884. ‡Francis, James B. Lowell, Massachusetts, U.S.A.
FRANCIS, WILLIAM, Ph.D., F.L.S., F.G.S., F.R.A.S. Red Lion-court, Fleet-street, London, E.C.; and Manor House, Richmond, Surrey.
1846. ‡FRANKLAND, EDWARD, M.D., D.C.L., LL.D., Ph.D., F.R.S., F.C.S. The Yews, Reigate Hill, Surrey.
*Frankland, Rev. Marmaduke Charles. Chowbent, near Manchester.
1882. ‡Fraser, Alexander, M.B. Royal College of Surgeons, Dublin.
1885. §FRASER, ANGUS, M.A., M.D., F.C.S. 232 Union-street, Aberdeen.
1859. ‡Fraser, George B. 3 Airlie-place, Dundee.
Fraser, James William. 8A Kensington Palace-gardens, London, W.
1865. *FRASER, JOHN, M.A., M.D. Chapel Ash, Wolverhampton.
1871. ‡FRASER, THOMAS R., M.D., F.R.S. L. & E., Professor of Materia Medica and Clinical Medicine in the University of Edinburgh. 37 Melville-street, Edinburgh.
1859. *Frazer, Daniel. 127 Buchanan-street, Glasgow.
1871. ‡Frazer, Evan L. R. Brunswick-terrace, Spring Bank, Hull.
1884. *Frazer, Persifor, M.A., D.Sc., Professor of Chemistry in the Franklin Institute of Pennsylvania. 917 Clinton-street, Philadelphia, U.S.A.
1884. *Fream, W., B.Sc., F.L.S., F.G.S., Professor of Natural History in the College of Agriculture, Downton, Salisbury.
1860. ‡Freeborn, Richard Fernandez. 38 Broad-street, Oxford.
1847. *Freeland, Humphrey William, F.G.S. West-street, Chichester.
1877. §Freeman, Francis Ford. 8 Leigham-terrace, Plymouth.
1865. ‡Freeman, James. 15 Francis-road, Edgbaston, Birmingham.
1880. ‡Freeman, Thomas. Brynhyfryd, Swansea.
1841. Freeth, Major-General S. 30 Royal-crescent, Notting Hill, London, W.
1884. *Fremantle, Hon. C. W., C.B. Royal Mint, London, E.
Frere, George Edward, F.R.S. Roydon Hall, Diss, Norfolk.
1869. ‡Frere, Rev. William Edward. The Rectory, Bilton, near Bristol.
1857. *Frith, Richard Hastings, C.E., M.R.I.A., F.R.G.S.I. 48 Summerhill, Dublin.

Year of Election.

1883. ‡Froane, William. Beech House, Birkdale, Southport.
1882. §Frost, Edward P., J.P. West Wratting Hall, Cambridgeshire.
1883. ‡Frost, Captain H., J.P. West Wratting, Cambridgeshire.
1875. ‡Fry, F. J. 104 Pembroke-road, Clifton, Bristol.
Fry, Francis. Cotham, Bristol.
1875. *Fry, Joseph Storrs. 2 Charlotte-street, Bristol.
1884. §Fryer, Joseph, J.P. Smelt House, Howden-le-Wear, Co. Durham.
1872. *Fuller, Rev. A. Pallant, Chichester.
1859. ‡FULLER, FREDERICK, M.A. 9 Palace-road, Surbiton.
1869. ‡FULLER, GEORGE, M.Inst.C.E. 71 Lexham-gardens, Kensington, London, W.
1884. §Fuller, William. Oswestry.
1864. *Furneaux, Rev. Alan. St. German's Parsonage, Cornwall.

1881. ‡Gabb, Rev. James, M.A. Bulmer Rectory, Welburn, Yorkshire.
*Gadesden, Augustus William, F.S.A. Ewell Castle, Surrey.
1857. ‡GAGES, ALPHONSE, M.R.I.A. Museum of Irish Industry, Dublin.
1863. *Gainsford, W. D. Aswardby Hall, Spilsby.
1876. ‡Gairdner, Charles. Broom, Newton Mearns, Renfrewshire.
1850. ‡Gairdner, Professor W. T., M.D. 225 St. Vincent-street, Glasgow.
1861. ‡Galbraith, Andrew. Glasgow.
GALBRAITH, Rev. J. A., M.A., M.R.I.A. Trinity College, Dublin.
1876. ‡Gale, James M. 23 Miller-street, Glasgow.
1863. ‡Gale, Samuel, F.C.S. 225 Oxford-street, London, W.
1885. *Gallaway, Alexander. Tighnault, Aberfeldy, N.B.
1861. ‡Galloway, Charles John. Knott Mill Iron Works, Manchester.
1861. ‡Galloway, John, jun. Knott Mill Iron Works, Manchester.
1875. ‡GALLOWAY, W. Cardiff.
1860. *GALTON, Captain DOUGLAS, C.B., D.C.L., LL.D., F.R.S., F.L.S., F.G.S., F.R.G.S. (GENERAL SECRETARY.) 12 Chester-street, Grosvenor-place, London, S.W.
1860. *GALTON, FRANCIS, M.A., F.R.S., F.G.S., F.R.G.S. 42 Rutland-gate, Knightsbridge, London, S.W.
1869. ‡GALTON, JOHN C., M.A., F.L.S. 40 Great Marlborough-street, London, W.
1870. §Gamble, Lieut.-Colonel D. St. Helen's, Lancashire.
1870. ‡Gamble, J. C. St. Helen's, Lancashire.
1872. *Gamble, John G., M.A. Capetown. (Care of Messrs. Ollivier and Brown, 37 Sackville-street, Piccadilly, London, W.)
1877. ‡Gamble, William. St. Helen's, Lancashire.
1868. ‡GAMGEE, ARTHUR, M.D., F.R.S., F.R.S.E., Fullerian Professor of Physiology in the Royal Institution, London. 11 Warrior-square, St. Leonard's-on-Sea.
1883. ‡Gant, Major John Castle. St. Leonard's.
1882. *Gardner, H. Dent, F.R.G.S. 25 Northbrook-road, Lee, Kent.
1882. §Gardner, John Starkie, F.G.S. 7 Damer-terrace, Chelsea, London, S.W.
1884. ‡Garman, Samuel. Cambridge, Massachusetts, U.S.A.
1862. ‡GARNER, ROBERT, F.L.S. Stoke-upon-Trent.
1865. ‡Garner, Mrs. Robert. Stoke-upon-Trent.
1882. ‡Garnett, William, M.A., Principal of the College of Physical Science, Newcastle-on-Tyne.
1873. ‡Garnham, John. Hazelwood, Crescent-road, St. John's, Brockley, Kent, S.E.
1883. §Garson, J. G., M.D. Royal College of Surgeons, Lincoln's-Inn-fields, London, W.C.

Year of Election.

1874. *Garstin, John Ribton, M.A., LL.B., M.R.I.A., F.S.A. Bragans-town, Castlebellingham, Ireland.
1882. ‡Garton, William. Woolston, Southampton.
1870. ‡Gaskell, Holbrook. Woolton Wood, Liverpool.
1870. *Gaskell, Holbrook, jun. Clayton Lodge, Aigburth, Liverpool.
1847. *Gaskell, Samuel. Church House, Weybridge.
1842. Gaskell, Rev. William, M.A. Plymouth-grove, Manchester.
1862. *Gatty, Charles Henry, M.A., F.L.S., F.G.S. Felbridge Place, East Grinstead, Sussex.
1875. ‡Gavey, J. 43 Stacey-road, Routh, Cardiff.
1875. ‡Gaye, Henry S., M.D. Newton Abbot, Devon.
1871. ‡Geddes, John. 9 Melville-crescent, Edinburgh.
1883. §Geddes, John. 33 Portland-street, Southport.
1885. §Geddes, Patrick. 81A Prince's-street, Edinburgh.
1859. ‡Geddes, William D., M.A., Professor of Greek in King's College, Old Aberdeen.
1854. ‡Gee, Robert, M.D. 5 Abercromby-square, Liverpool.
1867. ‡GEIKIE, ARCHIBALD, LL.D., F.R.S. L.&E., F.G.S., Director-General of the Geological Survey of the United Kingdom. Geological Survey Office, Jermyn-street, London, S.W.
1871. ‡Geikie, James, LL.D., F.R.S. L.&E., F.G.S., Murchison Professor of Geology and Mineralogy in the University of Edinburgh. 10 Bright's-crescent, Mayfield, Edinburgh.
1883. ‡Gell, Mrs. Seedley Lodge, Pendleton, Manchester.
1882. §Genese, R. W., M.A., Professor of Mathematics in University College, Aberystwith.
1875. *George, Rev. Hereford B., M.A., F.R.G.S. New College, Oxford.
1885. §Gerard, Robert. Blair-Devenick, Cults, Aberdeen.
1884. *Gerrans, Henry T., B.A. Worcester College, Oxford.
1870. ‡*Gerstl, R., F.C.S. University College, London, W.C.*
1870. *Gervis, Walter S., M.D., F.G.S. Ashburton, Devonshire.
1884. ‡Gibb, Charles. Abbotsford, Quebec, Canada.
1865. ‡Gibbins, William. Battery Works, Digbeth, Birmingham.
1874. ‡Gibson, The Right Hon. Edward, Q.C., M.P. 23 Fitzwilliam-square, Dublin.
1876. *Gibson, George Alexander, M.D., D.Sc., F.R.S.E. 17 Alva-street, Edinburgh.
1884. ‡Gibson, Rev. James J. 183 Spadina-avenue, Toronto, Canada.
1885. §Gibson, John, Ph.D. The University, Edinburgh.
1870. ‡*Gibson, Thomas.* 51 *Oxford-street, Liverpool.*
1870. ‡*Gibson, Thomas, jun.* 10 *Parkfield-road, Prince's Park, Liverpool.*
1884. ‡Gilbert, E. E. 245 St. Antoine-street, Montreal, Canada.
1842. GILBERT, JOSEPH HENRY, Ph.D., LL.D., F.R.S., F.C.S., Professor of Rural Economy in the University of Oxford. Harpenden, near St. Albans.
1883. §Gilbert, Mrs. Harpenden, near St. Albans.
1857. ‡Gilbert, J. T., M.R.I.A. Villa Nova, Blackrock, Dublin.
1884. *Gilbert, Philip H. 245 St. Antoine-street, Montreal, Canada.
1883. ‡Gilbert, Thomas. Derby-road, Southport.
1859. *GILCHRIST, JAMES, M.D. Crichton House, Dumfries.
Gilderdale, Rev. John, M.A. Walthamstow, Essex.
1882. ‡Giles, Alfred, M.P., M.I.C.E. Cosford, Godalming.
1878. ‡Giles, Oliver. Park Side, Cromwell-road, St. Andrew's, Bristol.
Giles, Rev. William. Netherleigh House, near Chester.
1878. ‡Gill, Rev. A. W. H. 44 Eaton-square, London, S.W.
1871. *GILL, DAVID, LL.D., F.R.S. Royal Observatory, Cape Town.

Year of
Election.

1868. ‡Gill, Joseph. Palermo, Sicily. (Care of W. H. Gill, Esq., General Post Office, St. Martin's-le-Grand, E.C.)
1864. ‡GILL, THOMAS. 4 Sydney-place, Bath.
1884. ‡Gillman, Henry. 79 East Columbia-street, Detroit, Michigan, U.S.A.
1861. *Gilroy, George. Woodlands, Parbold, near Wigan.
1867. ‡Gilroy, Robert. Craigie, by Dundee.
1876. ‡Gimingham, Charles H., F.C.S. 45 St. Augustine's-road, Camden-square, London, N.W.
1867. §GINSBURG, Rev. C. D., D.C.L., LL.D. Holmlea, Virginia Water Station, Chertsey.
1884. ‡Girdwood, Dr. G. P. 28 Beaver Hall-terrace, Montreal, Canada.
1874. *Girdwood, James Kennedy. Old Park, Belfast.
1884. ‡Gisborne, Frederick Newton. Ottawa, Canada.
1883. *Gladstone, Miss. 17 Pembridge-square, London, W.
1883. *Gladstone, Miss E. A. 17 Pembridge-square, London, W.
1850. *Gladstone, George, F.C.S., F.R.G.S. 31 Ventnor-villas, Brighton.
1883. *Gladstone, Miss Isabella M. 17 Pembridge-square, London, W.
1849. *GLADSTONE, JOHN HALL, Ph.D., F.R.S., F.C.S. 17 Pembridge-square, London, W.
1861. *GLAISHER, JAMES, F.R.S., F.R.A.S. 1 Dartmouth-place, Blackheath, London, S.E.
1871. *GLAISHER, J. W. L., M.A., F.R.S., F.R.A.S. Trinity College, Cambridge.
1883. ‡Glasson, L. T. 2 Roper-street, Penrith.
1881. *GLAZEBROOK, R. T., M.A., F.R.S. Trinity College, Cambridge.
1881. §Gleadow, Frederic. Brunswick House, Beverley-road, Hull.
1870. §Glen, David Corse, F.G.S. 14 Annfield-place, Glasgow.
1867. ‡Gloag, John A. L. 10 Inverleith-place, Edinburgh.
Glover, George. Ranelagh-road, Pimlico, London, S.W.
1874. ‡Glover, George T. 30 Donegall-place, Belfast.
1885. §Glover, John Moore. Brookfield, Lulworth-road, Southport.
Glover, Thomas. 124 Manchester-road, Southport.
1870. ‡Glynn, Thomas R. 1 Rodney-street, Liverpool.
1872. ‡GODDARD, RICHARD. 16 Booth-street, Bradford, Yorkshire.
1878. *Godlee, J. Lister. 3 New-square, Lincoln's Inn, London, W.C.
1880. ‡GODMAN, F. DU CANE, F.R.S., F.L.S., F.G.S. 10 Chandos-street, Cavendish-square, London, W.
1883. ‡Godson, Dr. Alfred. Cheadle, Cheshire.
1852. ‡Godwin, John. Wood House, Rostrevor, Belfast.
1879. ‡GODWIN-AUSTEN, Lieut.-Colonel H. H., F.R.S., F.R.G.S., F.Z.S. Shalford House, Guildford.
1876. ‡Goff, Bruce, M.D. Bothwell, Lanarkshire.
1877. ‡*Goff, James.* 11 *Northumberland-road, Dublin.*
1881. ‡Goldschmidt, Edward. Nottingham.
1873. ‡Goldthorp, Miss R. F. C. Cleckheaton, Bradford, Yorkshire.
1884. ‡Good, Charles E. 102 St. François Xavier-street, Montreal, Canada.
1878. ‡Good, Rev. Thomas, B.D. 51 Wellington-road, Dublin.
1852. ‡Goodbody, Jonathan. Clare, King's County, Ireland.
1884. ‡Goodbody, Robert. Fairy Hill, Blackrock, Co. Dublin.
1842. *GOODMAN, JOHN, M.D. 8 Leicester-street, Southport.
1885. §GOODMAN, J. D., J.P. Peachfield, Edgbaston, Birmingham.
1865. ‡Goodman, J. D. Minories, Birmingham.
1869. ‡Goodman, Neville, M.A. Peterhouse, Cambridge.
1884. §Goodridge, Richard E. W. Box No. 382, Post Office, Winnipeg, Canada.
1884. ‡Goodwin, Professor W. L. Kingston, Ontario, Canada.

Year of Election.

1870. *Goodwin, Rev. Henry Albert, M.A., F.R.A.S. Lambourne Rectory, Romford.
1883. ‡Goouch, B., B.A. 2 Oxford-road, Birkdale, Southport.
1885. §Gordon, General the Hon. Sir Alexander Hamilton. 50 Queen's Gate-gardens, London, S.W.
1885. §Gordon, Rev. Cosmo, D.D., F.R.A.S., F.G.S. Chetwynd Rectory, Newport, Salop.
1885. §Gordon, Rev. George, LL.D. Birnie, by Elgin, N.B.
1871. *Gordon, Joseph Gordon, F.C.S. Queen Anne's Mansions, Westminster, S.W.
1884. *Gordon, Robert, M.Inst.C.E., F.R.G.S. Howley Lodge, Maida Hill West, London, W.
1857. ‡Gordon, Samuel, M.D. 11 Hume-street, Dublin
1885. §Gordon, Rev. William. Braemar, N.B.
1865. ‡Gore, George, LL.D., F.R.S. 50 Islington-row, Edgbaston, Birmingham.
1875. *Gotch, Francis, B.A., B.Sc. Holywell Cottage, Oxford.
*Gotch, Rev. Frederick William, LL.D. Stokes Croft, Bristol.
*Gotch, Thomas Henry. Kettering.
1873. §Gott, Charles, M.Inst.C.E. Parkfield-road, Manningham, Bradford Yorkshire.
1849. ‡Gough, The Hon. Frederick. Perry Hall, Birmingham.
1857. ‡Gough, The Right Hon. George S., Viscount, M.A., F.L.S., F.G.S. St. Helen's, Booterstown, Dublin.
1881. ‡Gough, Thomas, B.Sc., F.C.S. Elmfield College, York.
1868. ‡Gould, Rev. George. Unthank-road, Norwich.
1873. ‡Gourlay, J. McMillan. 21 St. Andrew's-place, Bradford, Yorkshire.
1867. ‡Gourley, Henry (Engineer). Dundee.
1876. ‡Gow, Robert. Cairndowan, Dowanhill, Glasgow.
1883. §Gow, Mrs. Cairndowan, Dowanhill, Glasgow.
Gowland, James. London-wall, London, E.C.
1873. §Goyder, Dr. D. Marley House, 88 Great Horton-road, Bradford, Yorkshire.
1861. ‡Grafton, Frederick W. Park-road, Whalley Range, Manchester.
1867. *GRAHAM, CYRIL, C.M.G., F.L.S., F.R.G.S. Travellers' Club, Pall Mall, London, S.W.
1875. ‡GRAHAME, JAMES. 12 St. Vincent-street, Glasgow.
1852. *GRAINGER, Rev. Canon JOHN, D.D., M.R.I.A. Skerry and Rathcavan Rectory, Broughshane, near Ballymena, Co. Antrim.
1870. ‡GRANT, Colonel JAMES A., C.B., C.S.I., F.R.S., F.L.S., F.R.G.S. 19 Upper Grosvenor-street, London, W.
1855. *GRANT, ROBERT, M.A., LL.D., F.R.S., F.R.A.S., Regius Professor of Astronomy in the University of Glasgow. The Observatory, Glasgow.
1854. ‡GRANTHAM, RICHARD B., M.Inst.C.E., F.G.S. Northumberland-chambers, Northumberland-avenue, London, W.C.
1864. ‡Grantham, Richard F. Northumberland-chambers, Northumberland-avenue, London, W.C.
1881. ‡Graves, E. 22 Trebovir-road, Earl's Court-road, London, S.W.
1874. ‡Graves, Rev. James, B.A., M.R.I.A. Inisnag Glebe, Stonyford, Co. Kilkenny.
1881. ‡Gray, Alan, LL.B. Minster-yard, York.
1870. ‡*Gray, C. B. 5 Rumford-place, Liverpool.*
1864. *Gray, Rev. Charles. The Vicarage, Blyth, Worksop.
1865. ‡Gray, Charles. Swan-bank, Bilston.
1876. ‡Gray, Dr. Newton-terrace, Glasgow.
1881. ‡Gray, Edwin, LL.B. Minster-yard, York.

Year of
Election.

1864. ‡*Gray, Jonathan. Summerhill House, Bath.*
1859. ‡Gray, Rev. J. H. Bolsover Castle, Derbyshire.
1881. ‡*Gray, Thomas. 21 Haybrom-crescent, Glasgow.*
1883. ‡Gray, Thomas. Spittal Hill, Morpeth.
1873. ‡Gray, William, M.R.I.A. 6 Mount Charles, Belfast.
*GRAY, Colonel WILLIAM. Farley Hall, near Reading.
1883. ‡Gray, William Lewis. 36 Gutter-lane, London, E.C.
1883. ‡Gray, Mrs. W. L. 36 Gutter-lane, London, E.C.
1883. ‡Greathead, J. H. 8 Victoria-chambers, London, S.W.
1866. §Greaves, Charles Augustus, M.B., LL.B. 101 Friar-gate, Derby.
1869. ‡Greaves, William. Station-street, Nottingham.
1872. ‡Greaves, William. 3 South-square, Gray's Inn, London, W.C.
1872. *Grece, Clair J., LL.D. Redhill, Surrey.
1879. ‡Green, A. F. 15 Ashwood-villas, Headingley, Leeds.
1858. *Greenhalgh, Thomas. Thornydikes, Sharples, near Bolton-le-Moors.
1882. ‡GREENHILL, A. G., M.A., Professor of Mathematics at the Royal Artillery Institution, Woolwich. Emmanuel College, Cambridge.
1881. §Greenhough, Edward. Matlock Bath, Derbyshire.
1884. ‡Greenish, Thomas, F.C.S. 20 New-street, Dorset-square, London, N.W.
1884. ‡Greenshields, E. B. Montreal, Canada.
1884. ‡Greenshields, Samuel. Montreal, Canada.
1863. ‡Greenwell, G. E. Poynton, Cheshire.
1875. ‡Greenwood, Frederick. School of Medicine, Leeds.
1862. *Greenwood, Henry. 32 Castle-street, and the Woodlands, Anfield-road, Anfield, Liverpool.
1877. ‡Greenwood, Holmes. 78 King-street, Accrington.
1883. ‡GREENWOOD, J. G., LL.D., Vice-Chancellor of Victoria University. Owens College, Manchester.
1849. ‡Greenwood, William. Stones, Todmorden.
1861. *GREG, ROBERT PHILIPS, F.G.S., F.R.A.S. Coles Park, Buntingford, Herts.
1833. Gregg, T. H. 22 Ironmonger-lane, Cheapside, London, E.C.
1860. ‡GREGOR, Rev. WALTER, M.A. Pitsligo, Rosehearty, Aberdeenshire.
1868. ‡Gregory, Charles Hutton, C.M.G. 2 Delahay-street, Westminster, S.W.
1883. ‡Gregson, Edward, Ribble View, Preston.
1883. ‡Gregson, G. E. Ribble View, Preston.
1861. *Gregson, Samuel Leigh. Aigburth-road, Liverpool.
1881. §Gregson, William. Baldersby, Thirsk.
1875. ‡Grenfell, J. Granville, B.A., F.G.S. 5 Albert-villas, Clifton, Bristol.
1875. ‡Grey, Mrs. Maria G. 18 Cadogan-place, London, S.W.
1871. *Grierson, Samuel, Medical Superintendent of the District Asylum, Melrose, N.B.
1859. ‡GRIERSON, THOMAS BOYLE, M.D. Thornhill, Dumfriesshire.
1875. ‡Grieve, David, F.R.S.E., F.G.S. 2 Victoria-terrace, Portobello, Edinburgh.
1878. ‡Griffin, Robert, M.A., LL.D. Trinity College, Dublin.
1859. *GRIFFITH, GEORGE, M.A., F.C.S. Harrow.
1870. ‡Griffith, Rev. Henry, F.G.S. Barnet, Herts.
1884. §Griffiths, E. H. 12 Park-side, Cambridge.
1884. §Griffiths, Mrs. 12 Park-side, Cambridge.
1847. ‡Griffiths, Thomas. Bradford-street, Birmingham.
1879. §Griffiths, Thomas, F.C.S., F.S.S. Heidelberg House, King's-road, Clapham Park, London, S.W.
1875. ‡Grignon, James, H.M. Consul at Riga. Riga.

Year of Election.

1870. ‡Grimsdale, T. F., M.D. 29 Rodney-street, Liverpool.
1884. ‡Grinnell, Frederick. Providence, Rhode Island, U.S.A.
1881. ‡Gripper, Edward. Nottingham.
1864. ‡GROOM-NAPIER, CHARLES OTTLEY. 18 Elgin-road, St. Peter's Park, London, N.W.
1869. §Grote, Arthur, F.L.S., F.G.S. 42 Ovington-square, London, S.W.
GROVE, The Hon. Sir WILLIAM ROBERT, Knt., M.A., D.C.L., LL.D., F.R.S. 115 Harley-street, London, W.
1863. *GROVES, THOMAS B., F.C.S. 80 St. Mary-street, Weymouth.
1869. ‡GRUBB, HOWARD, F.R.S., F.R.A.S. 141 Leinster-road, Rathmines, Dublin.
1886. §Grundy, John. Park Drive, Nottingham.
1867. ‡Guild, John. Bayfield, West Ferry, Dundee.
Guinness, Henry. 17 College-green, Dublin.
1842. Guinness, Richard Seymour. 17 College-green, Dublin.
1856. *GUISE, Lieut.-Colonel Sir WILLIAM VERNON, Bart., F.G.S., F.L.S. Elmore Court, near Gloucester.
1862. ‡Gunn, John, M.A., F.G.S. Irstedd Rectory, Norwich.
1885. §Gunn, John. Dale, Halkirk, Caithness.
1877. ‡Gunn, William, F.G.S. Office of the Geological Survey of Scotland, Sheriff's Court House, Edinburgh.
1866. ‡GÜNTHER, ALBERT C. L. G., M.A., M.D., Ph.D., F.R.S., Keeper of the Zoological Collections in the British Museum. British Museum, South Kensington, S.W.
1880. §Guppy, John J. Ivy-place, High-street, Swansea
1868. *Gurney, John. Sprouston Hall, Norwich.
1876. ‡Guthrie, Francis. Cape Town, Cape of Good Hope.
1859. ‡GUTHRIE, FREDERICK, B.A., F.R.S. L. & E., F.G.S., Professor of Physics in the Royal School of Mines. Science Schools, South Kensington, London, S.W.
1883. ‡Guthrie, Malcolm. 2 Parkfield-road, Liverpool.
1857. ‡Gwynne, Rev. John. Tullyagnish, Letterkenny, Strabane, Ireland.
1876. ‡GWYTHER, R. F., M.A. Owens College, Manchester.

1884. ‡Haanel, E., Ph.D. Cobourg, Ontario, Canada.
1865. ‡Hackney, William. 9 Victoria-chambers, Victoria-street, London, S.W.
1884. ‡Hadden, Captain C. F., R.A. Woolwich.
1881. *HADDON, ALFRED CORT, B.A., F.Z.S., Professor of Zoology in the Royal College of Science, Dublin.
Haden, G. N. Trowbridge, Wiltshire.
1842. Hadfield, George. Victoria-park, Manchester.
1870. ‡*Hadivan, Isaac. 3 Huskisson-street, Liverpool.*
1848. ‡Hadland, William Jenkins. Banbury, Oxfordshire.
1870. ‡Haigh, George. Waterloo, Liverpool.
*Hailstone, Edward, F.S.A. Walton Hall, Wakefield, Yorkshire.
1879. ‡HAKE, H. WILSON, Ph.D., F.C.S. Queenwood College, Hants.
1875. ‡Hale, Rev. Edward, M.A., F.G.S., F.R.G.S. Eton College, Windsor.
1883. ‡Haliburton, Robert Grant. National Club, Whitehall, London, S.W.
1872. ‡Hall, Dr. Alfred. 8 Mount Ephraim, Tunbridge Wells.
1879. *Hall, Ebenezer. Abbeydale Park, near Sheffield.
1883. **Hall, Miss Emily. Bowdon, Cheshire.*
1881. ‡Hall, Frederick Thomas, F.R.A.S. 15 Gray's Inn-square, London, W.C.
1854. *HALL, HUGH FERGIE, F.G.S. Greenheys, Wallasey, Birkenhead.
1872. *Hall, Captain Marshall, F.G.S. St. John's, Bovey Tracey, South Devon.

Year of Election.

1885. §Hall, Samuel. 19 Aberdeen Park, Highbury, London, N.
*Hall, Thomas B. Australia. (Care of J. P. Hall, Esq., Crane House, Great Yarmouth.)
1884. ‡Hall, Thomas Proctor. School of Practical Science, Toronto, Canada.
1866. *HALL, TOWNSHEND M., F.G.S. Pilton, Barnstaple.
1860. ‡Hall, Walter. 11 Pier-road, Erith.
1883. *Hall, Miss Wilhelmina. The Gore, Eastbourne.
1873. *HALLETT, T. G. P., M.A. Claverton Lodge, Bath.
1868. *HALLETT, WILLIAM HENRY, F.L.S. Buckingham House, Marine Parade, Brighton.
Halsall, Edward. 4 Somerset-street, Kingsdown, Bristol.
1858. *Hambly, Charles Hambly Burbridge, F.G.S. Holmeside, Hazelwood, Derby.
1883. *Hamel, Egbert D. de. Bole Hall, Tamworth.
1885. §Hamilton, David James. 1A Albyn-place, Aberdeen.
1869. §Hamilton, Rowland. Oriental Club, Hanover-square, London, W.
1851. ‡Hammond, C. C. Lower Brook-street, Ipswich.
1881. *Hammond, Robert. Hilldrop, Highgate, London, N.
1878. ‡Hanagan, Anthony. Luckington, Dalkey.
1878. §Hance, Edward M., LL.B. 6 Sea Bank-avenue, Egremont, Cheshire.
1875. ‡*Hancock, C. F., M.A. 36 Blandford-square, London, N.W.*
1863. ‡Hancock, John. 4 St. Mary's-terrace, Newcastle-on-Tyne.
1850. ‡Hancock, John, J.P. The Manor House, Lurgan, Co. Armagh.
1861. ‡Hancock, Walter. 10 Upper Chadwell-street, Pentonville, London, N.
1857. ‡Hancock, William J. 23 Synnot-place, Dublin.
1847. ‡HANCOCK, W. NEILSON, LL.D., M.R.I.A. 64 Upper Gardiner-street, Dublin.
1876. ‡Hancock, Mrs. W. Neilson. 64 Upper Gardiner-street, Dublin.
1865. ‡*Hands, M. Coventry.*
1882. ‡Hankinson, R. C. Bassett, Southampton.
1884. §Hannaford, E. C. 1591 Catherine-street, Montreal, Canada.
1859. ‡Hannay, John. Montcoffer House, Aberdeen.
1853. ‡*Hansell, Thomas T. 2 Charlotte-street, Sculcoates, Hull.*
*HARCOURT, A. G. VERNON, M.A., LL.D., F.R.S., F.C.S. (GENERAL SECRETARY.) Cowley Grange, Oxford.
1884. *Hardcastle, Norman C., M.A., LL.M. Downing College, Cambridge.
1865. ‡Harding, Charles. Harborne Heath, Birmingham.
1869. ‡Harding, Joseph. Millbrooke House, Exeter.
1877. ‡Harding, Stephen. Bower Ashton, Clifton, Bristol.
1869. ‡Harding, William D. Islington Lodge, King's Lynn, Norfolk.
1874. ‡Hardman, E. T., F.C.S. 14 Hume-street, Dublin.
1872. ‡Hardwicke, Mrs. 192 Piccadilly, London, W.
1880. ‡Hardy, John. 118 Embden-street, Manchester.
*HARE, CHARLES JOHN, M.D. Berkeley House, 15 Manchester-square, London, W.
1858. ‡Hargrave, James. Burley, near Leeds.
1883. §Hargreaves, Miss H. M. 69 Alexandra-road, Southport.
1883. ‡Hargreaves, Thomas. 69 Alexandra-road, Southport.
1881. ‡Hargrove, William Wallace. St. Mary's, Bootham, York.
1876. ‡Harker, Allen, F.L.S., Professor of Natural History in the Royal Agricultural College, Cirencester.
1878. *Harkness, H. W. California Academy of Sciences, San Francisco, California, U.S.A.
1871. §Harkness, William. Laboratory, Somerset House, London, W.C.

Year of Election.

1875. *Harland, Rev. Albert Augustus, M.A., F.G.S., F.L.S., F.S.A. The Vicarage, Harefield, Middlesex.
1877. *Harland, Henry Seaton. Stanbridge, Staplefield, Crawley, Sussex.
1883. ‡Harland, Miss S. 25 Acomb-street, Greenheys, Manchester.
1883. *Harley, Miss Clara. 96 Netherwood-road, London, W.
1862. *HARLEY, GEORGE, M.D., F.R.S., F.C.S. 25 Harley-street, London, W.
1883. *Harley, Harold. 14 Chapel-street, Bedford-row, London, W.C.
1862. *HARLEY, Rev. ROBERT, F.R.S., F.R.A.S. 96 Netherwood-road, London, W.
1868. *HARMER, F. W., F.G.S. Oakland House, Cringleford, Norwich.
1881. *HARMER, SIDNEY F., B.Sc. King's College, Cambridge.
1882. ‡Harper, G. T. Bryn Hyfrydd, Portswood, Southampton.
1872. ‡Harpley, Rev. William, M.A. Clayhanger Rectory, Tiverton.
1884. ‡Harrington, B. J., B.A., Ph.D., Professor of Chemistry and Mineralogy in McGill College, Montreal. Wallbrac-place, Montreal, Canada.
1872. *Harris, Alfred. Lunefield, Kirkby-Lonsdale, Westmoreland.
1883. §Harris, Charles, F.R.G.S. Derwent Villa, Whalley Range, Manchester.
1871. ‡HARRIS, GEORGE, F.S.A. Iselipps Manor, Northolt, Southall, Middlesex.
1842. *Harris, G. W., M.Inst.C.E. Mount Gambier, South Australia.
1884. §Harris, Miss Katherine E. 75 Linden-gardens, Bayswater, London, W.
1860. ‡*Harrison, Rev. Francis, M.A. Oriel College, Oxford.*
1885. §Harrison, Sir George. 7 Whitehouse-terrace, Edinburgh.
1864. ‡Harrison, George. Barnsley, Yorkshire.
1873. ‡*Harrison, George, Ph.D., F.L.S., F.C.S. 96, Northgate, Huddersfield.*
1874. ‡Harrison, G. D. B. 3 Beaufort-road, Clifton, Bristol.
1858. *HARRISON, JAMES PARK, M.A. 22 Connaught-street, Hyde Park, London, W.
1870. ‡HARRISON, REGINALD. 51 Rodney-street, Liverpool.
1853. ‡Harrison, Robert. 36 George-street, Hull.
1863. ‡Harrison, T. E. Engineers' Office, Central Station, Newcastle-on-Tyne.
1883. ‡Harrison, Thomas. 34 Ash-street, Southport.
1854. ‡Harrowby, The Right Hon. the Earl of. 39 Grosvenor-square, London, W.; and Sandon Hall, Lichfield.
1885. §HART, CHARLES J. 28 George-road, Edgbaston, Birmingham.
1876. *Hart, Thomas. Brooklands, Blackburn.
1881. §Hart, Thomas, F.G.S. Yewbarrow, Grange-over-Sands, Carnforth.
1875. ‡Hart, W. E. Kilderry, near Londonderry.
Hartley, James. Sunderland.
1871. ‡HARTLEY, WALTER NOEL, F.R.S. L. & E., F.C.S., Professor of Chemistry in the Royal College of Science, Dublin.
1854. §HARTNUP, JOHN, F.R.A.S. Liverpool Observatory, Bidston, Birkenhead.
1870. ‡Harvey, Enoch. Riversdale-road, Aigburth, Liverpool.
Harvey, J. R., M.D. St. Patrick's-place, Cork.
1885. §Harvey, Surgeon Major Robert, M.D. Calcutta.
1885. §Harvie-Brown, J. A. Dunipace, Larbert, N.B.
1862. *Harwood, John, jun. Woodside Mills, Bolton-le-Moors.
1884. §Haslam, Rev. George, M.A. Trinity College, Toronto, Canada.
1882. §Haslam, George James, M.D. Owens College, Manchester.
1875. ‡HASTINGS, G. W., M.P. Barnard's Green House, Malvern.

Year of
Election.

1857. ‡HAUGHTON, Rev. SAMUEL, M.A., M.D., D.C.L., LL.D., F.R.S., M.R.I.A., F.G.S., Senior Fellow of Trinity College, Dublin. Dublin.
1874. ‡Hawkins, B. Waterhouse, F.G.S. Century Club, East Fifteenth-street, New York.
1872. *Hawkshaw, Henry Paul. 58 Jermyn-street, St. James's, London, S.W.
*HAWKSHAW, Sir JOHN, M.Inst.C.E., F.R.S., F.G.S., F.R.G.S. Hollycombe, Liphook, Petersfield; and 33 Great George-street, London, S.W.
1864. *HAWKSHAW, JOHN CLARKE, M.A., M.Inst.C.E., F.G.S. 50 Harrington-gardens, South Kensington, S.W.; and 33 Great George-street London, S.W.
1868. §HAWKSLEY, THOMAS, M.Inst.C.E., F.R.S., F.G.S. 30 Great George-street, London, S.W.
1884. *Haworth, Abraham. Hilston House, Altrincham.
1863. ‡Hawthorn, William. The Cottage, Benwell, Newcastle-upon-Tyne.
1859. ‡Hay, Sir Andrew Leith, Bart. Rannes, Aberdeenshire.
1877. ‡Hay, Arthur J. Lerwick, Shetland.
1861. *HAY, Admiral the Right Hon. Sir JOHN C. D., Bart., K.C.B., D.C.L., F.R.S. 108 St. George's-square, London, S.W.
1858. ‡Hay, Samuel. Albion-place, Leeds.
1867. ‡Hay, William. 21 Magdalen-yard-road, Dundee.
1885. *Haycraft, John Berry, M.B., B.Sc., F.R.S.E., Professor of Physiology in Mason Science College, Birmingham.
1873. *Hayes, Rev. William A., M.A. Dromore, Co. Down, Ireland.
1869. ‡Hayward, J. High-street, Exeter.
1858. *HAYWARD, ROBERT BALDWIN, M.A., F.R.S. The Park, Harrow.
1879. *Hazlehurst, George S. Rhyl, North Wales.
1851. §HEAD, JEREMIAH, M.Inst.C.E., F.C.S. Middlesbrough, Yorkshire.
1869. ‡Head, R. T. The Briars, Alphington, Exeter.
1883. ‡Headley, Frederick Halcombe. Manor House, Petersham, S.W.
1883. ‡Headley, Mrs. Marian. Manor House, Petersham, S.W.
1883. §Headley, Rev. Tanfield George. Manor House, Petersham, S.W.
1863. ‡*Heald, Joseph. 22 Leazes-terrace, Newcastle-on-Tyne.*
1871. §Healey, George. Brantfield, Bowness, Windermere.
1883. *Heap, Ralph, jun. 2 Lulworth-road, Birkdale, Southport.
1861. *Heape, Benjamin. Northwood, Prestwich, near Manchester.
1883. ‡Heape, Charles. 14 Hawkshead-street, Southport.
1883. ‡Heape, Joseph R. 96 Mereland-terrace, Rochdale.
1882. *Heape, Walter. New Museums, Cambridge.
1877. ‡Hearder, Henry Pollington. Westwell-street, Plymouth.
1865. ‡Hearder, William. Rocombe, Torquay.
1877. ‡Hearder, William Keep, F.S.A. 195 Union-street, Plymouth.
1883. ‡Heath, Dr. 46 Hoghton-street, Southport.
1866. ‡Heath, Rev. D. J. Esher, Surrey.
1863. ‡Heath, G. Y., M.D. Westgate-street, Newcastle-on-Tyne.
1884. §Heath, Thomas, B.A. Royal Observatory, Calton Hill, Edinburgh.
1861. ‡HEATHFIELD, W. E., F.C.S., F.R.G.S., F.R.S.E. 1 Powis-grove, Brighton; and Arthur's Club, St. James's, London, S.W.
1883. ‡Heaton, Charles. Marlborough House, Hesketh Park, Southport.
1865. ‡Heaton, Harry. Harborne House, Harborne, near Birmingham.
1884. §Heaviside, Rev. George, B.A., F.R.G.S. The Hollies, Stoke Green, Coventry.
1833. ‡HEAVISIDE, Rev. Canon J. W. L., M.A. The Close, Norwich.
1855. ‡HECTOR, JAMES, M.D., F.R.S., F.G.S., F.R.G.S., Director of the Geological Survey of New Zealand. Wellington, New Zealand.

Year of
Election.

1867. ‡Heddle, M. Forster, M.D., F.R.S.E. St. Andrews, N.B.
1869. ‡Hedgeland, Rev. W. J. 21 Mount Radford, Exeter.
1882. ‡Hedger, Philip. Cumberland-place, Southampton.
1863. ‡Hedley, Thomas. Cox Lodge, near Newcastle-on-Tyne.
1867. ‡Henderson, Alexander. Dundee.
1873. *Henderson, A. L. 49 King William-street, London, E.C.
1883. §Henderson, Mrs. A. L. 49 King William-street, London, E.C.
1880. *Henderson, Commander W. H., R.N. Upton House, Sandwich.
1876. *Henderson, William. Williamfield, Irvine, N.B.
1885. §Henderson, William. Devanha House, Aberdeen.
1856. ‡HENNESSY, HENRY G., F.R.S., M.R.I.A., Professor of Applied Mathematics and Mechanics in the Royal College of Science for Ireland. Brookvale, Donnybrook, Co. Dublin.
1857. ‡Hennessy, Sir John Pope, K.C.M.G., Governor and Commander-in-Chief of Mauritius.
1873. *HENRICI, OLAUS M. F. E., Ph.D., F.R.S., Professor of Mechanics and Mathematics in the City and Guilds of London Institute. Elm Lodge, Elm Row, Hampstead, London, N.W.
Henry, Franklin. Portland-street, Manchester.
1873. Henry, J. Snowdon. East Dene, Bonchurch, Isle of Wight.
Henry, Mitchell, M.P. Stratheden House, Hyde Park, London, W.
*HENRY, WILLIAM CHARLES, M.D., F.R.S., F.G.S., F.R.G.S., F.C.S. Haffield, near Ledbury, Herefordshire.
1884. ‡Henshaw, George H. 43 Victoria-street, Montreal, Canada.
1870. ‡Henty, William. 12 Medina-villas, Brighton.
1855. *Hepburn, J. Gotch, LL.B., F.C.S. Dartford, Kent.
1855. ‡Hepburn, Robert. 9 Portland-place, London, W.
Hepburn, Thomas. Clapham, London, W.
1882. §Herbert, The Hon. Auberon. Ashley, Arnewood Farm, Lymington.
1866. ‡Herrick, Perry. Bean Manor Park, Loughborough.
1871. *HERSCHEL, Professor ALEXANDER S., M.A., F.R.S., F.R.A.S. College of Science, Newcastle-on-Tyne.
1883. ‡Herschel, Miss F. Collingwood, Hawkhurst, Kent.
1874. §HERSCHEL, Lieut.-Colonel JOHN, R.E., F.R.S., F.R.A.S. Collingwood, Hawkhurst, Kent.
1883. ‡Hesketh, Colonel E. Fleetwood. Meol's Hall, Southport.
1865. ‡Heslop, Dr. Birmingham.
1884. §Hewett, George Edwin. The Leasowe, Cheltenham.
1883. §Hewson, Thomas. Care of J. C. C. Payne, Esq., Botanic-avenue, The Plains, Belfast.
1881. ‡Hey, Rev. William Croser, M.A. Clifton, York.
1882. ‡Heycock, Charles T., B.A. King's College, Cambridge.
1883. §Heyes, John Frederick, M.A., F.C.S., F.R.G.S. 12 Merton-street, Oxford.
1866. *Heymann, Albert. West Bridgford, Nottinghamshire.
1866. ‡Heymann, L. West Bridgford, Nottinghamshire.
1879. ‡Heywood, A. Percival. Duffield Bank, Derby.
1861. *Heywood, Arthur Henry. Elleray, Windermere.
*HEYWOOD, JAMES, F.R.S., F.G.S., F.S.A., F.R.G.S., F.S.S. 26 Kensington Palace-gardens, London, W.
1861. *Heywood, Oliver. Claremont, Manchester.
Heywood, Thomas Percival. Claremont, Manchester.
1881. §Hick, Thomas, B.A., B.Sc. 2 George's-terrace, Harrogate.
1875. ‡HICKS, HENRY, M.D., F.R.S., F.G.S. Hendon Grove, Hendon, Middlesex, N.W.
1877. §HICKS, Professor W. M., M.A., F.R.S., Principal of Firth College, Sheffield. Endcliffe-crescent, Sheffield.

Year of
Election.

1884. ‡Hickson, Joseph. Montreal, Canada.
1864. *Hiern, W. P., M.A. Castle House, Barnstaple.
1861. *Higgin, James. Lancaster-avenue, Fennel-street, Manchester.
1875. ‡Higgins, Charles Hayes, M.D., M.R.C.P., F.R.C.S., F.R.S.E. Alfred House, Birkenhead.
1871. ‡Higgins, Clement, B.A., F.C.S. 103 Holland-road, Kensington, London, W.
1854. ‡Higgins, Rev. Henry H., M.A. The Asylum, Rainhill, Liverpool.
Hildyard, Rev. James, B.D., F.C.P.S. Ingoldsby, near Grantham, Lincolnshire.
1885. *Hill, Alexander, M.A., M.B. Grantchester, near Cambridge.
Hill, Arthur. Bruce Castle, Tottenham, Middlesex.
1880. ‡Hill, Benjamin. Cwmdwr, near Clydach, Swansea.
1883. §Hill, Berkeley, M.B., Professor of Clinical Surgery in University College, London. 66 Wimpole-street, London, W.
1872. §Hill, Charles, F S.A. Rockhurst, West Hoathley, East Grinstead.
1881. §Hill, Rev. Edwin, M.A., F.G.S. St. John's College, Cambridge.
1884. ‡Hill, Rev. James Edgar, M.A., B.D. 1516 St. Catherine-street, Montreal, Canada.
1857. §Hill, John, C.E., M.R.I.A., F.R.G.S.I. County Surveyor's Office, Ennis, Ireland.
1871. ‡Hill, Lawrence. The Knowe, Greenock.
1881. ‡Hill, Pearson. 50 Belsize Park, London, N.W.
1872. *Hill, Rev. Canon, M.A., F.G.S. Sheering Rectory, Harlow.
1885. *Hill, Sidney. Langford House, Langford, Bristol.
1876. ‡Hill, William H. Barlanark, Shettleston, N.B.
1885. *Hillhouse, William, M.A., Professor of Botany in Mason Science College, Birmingham. 95 Harborne-road, Edgbaston, Birmingham.
1863. ‡Hills, F. C. Chemical Works, Deptford, Kent, S.E.
1871. *Hills, Thomas Hyde. 225 Oxford-street, London, W.
1858. ‡Hincks, Rev. Thomas, B.A., F.R.S. Stancliff House, Clevedon, Somerset.
1870. ‡Hinde, G. J., Ph.D., F.G.S. 11 Glebe-villas, Mitcham, Surrey.
1883. *Hindle, James Henry. 67 Avenue-parade, Accrington.
*Hindmarsh, Luke. Alnbank House, Alnwick.
1865. ‡Hinds, James, M.D. Queen's College, Birmingham.
1863. ‡Hinds, William, M.D. Parade, Birmingham.
1881. ‡Hingston, J. T. Clifton, York.
1884. ‡Hingston, William Hales, M.D., D.C.L. 37 Union Avenue, Montreal, Canada.
1884. §Hirschfilder, C. A. Toronto, Canada.
1858. ‡Hirst, John, jun. Dobcross, near Manchester.
1861. *Hirst, T. Archer, Ph.D., F.R.S., F.R.A.S. 7 Oxford and Cambridge Mansions, Marylebone-road, London, N.W.
1870. ‡Hitchman, William, M.D., LL.D., F.L.S. 29 Erskine-street, Liverpool.
1884. ‡Hoadrey, John Chipman. Boston, Massachusetts, U.S.A.
Hoare, J. Gurney. Hampstead, London, N.W.
1881. §Hobbes, Robert George. The Dockyard, Chatham.
1864. ‡Hobhouse, Arthur Fane. 24 Cadogan-place, London, S.W.
1864. ‡Hobhouse, Charles Parry. 24 Cadogan-place, London, S.W.
1864. ‡Hobhouse, Henry William. 24 Cadogan-place, London, S.W.
1879. §Hobkirk, Charles P., F.L.S. West Riding Union Bank, Dewsbury.
1883. ‡Hobson, Rev. E. W. 55 Albert-road, Southport.
1879. §Hobson, John. Tapton Elms, Sheffield.
1877. ‡Hockin, Edward. Poughill, Stratton, Cornwall.

Year of Election

1883. ‡Hocking, Rev. Silas K. 21 Scarisbrick New-road, Southport.
1877. ‡Hodge, Rev. John Mackey, M.A. 38 Tavistock-place, Plymouth.
1876. ‡Hodges, Frederick W. Queen's College, Belfast.
1852. ‡Hodges, John F., M.D., F.C.S., Professor of Agriculture in Queen's College, Belfast.
1863. *HODGKIN, THOMAS. Benwell Dene, Newcastle-on-Tyne.
1880. §Hodgkinson, W. R. Eaton, Ph.D. Science Schools, South Kensington Museum, London, S.W.
1873. *Hodgson, George. Thornton-road, Bradford, Yorkshire.
1873. ‡Hodgson, James. Oakfield, Manningham, Bradford, Yorkshire.
1884. ‡Hodgson, Jonathan. Montreal, Canada.
1863. ‡Hodgson, Robert. Whitburn, Sunderland.
1863. ‡Hodgson, R. W. North Dene, Gateshead.
1865. *HOFMANN, AUGUST WILHELM, M.D., LL.D., Ph.D., F.R.S., F.C.S. 10 Dorotheen Strasse, Berlin.
1854. *Holcroft, George. Byron's-court, St. Mary's-gate, Manchester.
1883. ‡Holden, Edward. Laurel Mount, Shipley, Yorkshire.
1873. *Holden, Isaac, M.P. Oakworth House, near Keighley, Yorkshire.
1883. ‡Holden, James. 12 Park-avenue, Southport.
1883. ‡Holden, John J. 23 Duke-street, Southport.
1884. ‡Holden, Mrs. Mary E. Dunham Ladies' College, Quebec, Canada.
1879. ‡*Holland, Calvert Bernard. Ashdell, Broomhill, Sheffield.*
*Holland, Philip H. 3 Heath-rise, Willow-road, Hampstead, London, N.W.
1865. ‡Holliday, William. New-street, Birmingham.
1883. ‡Hollingsworth, Dr. T. S. Elford Lodge, Spring-grove, Isleworth, Middlesex.
1866. *Holmes, Charles. 59 London-road, Derby.
1873. ‡Holmes, J. R. Southbrook Lodge, Bradford, Yorkshire.
1882. *Holmes, Thomas Vincent, F.G.S. 28 Croom's-hill, Greenwich, S.E.
1876. ‡*Holms, Colonel William, M.P. 95 Cromwell-road, South Kensington, London, S.W.*
1870. ‡Holt, William D. 23 Edge-lane, Liverpool.
1875. *Hood, John. The Elms, Cotham Hill, Bristol.
1847. ‡HOOKER, Sir JOSEPH DALTON, K.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S., V.P.L.S., F.G.S., F.R.G.S. The Camp, Sunningdale.
1865. *Hooper, John P. Coventry Park, Streatham, London, S.W.
1877. *Hooper, Rev. Samuel F., M.A. 39 Lorrimore-square, London, S.E.
1856. ‡Hooton, Jonathan. 80 Great Ducie-street, Manchester.
1842. Hope, Thomas Arthur. Stanton, Bebington, Cheshire.
1884. *Hopkins, Edward M. 3 Upper Berkeley-street, Portman-square, London, W.
1865. ‡Hopkins, J. S. Jesmond Grove, Edgbaston, Birmingham.
1884. *Hopkinson, Charles. 29 Princess-street, Manchester.
1882. *Hopkinson, Edward, D.Sc. Grove House, Oxford-road, Manchester.
1870. *HOPKINSON, JOHN, M.A., D.Sc., F.R.S. 3 Holland Villas-road, Kensington, London, W.
1871. *HOPKINSON, JOHN, F.L.S., F.G.S. 95 New Bond-street, London, W.; and Wansford House, Watford.
1858. ‡Hopkinson, Joseph, jun. Britannia Works, Huddersfield.
Hornby, Hugh. Sandown, Liverpool.
1885. §Horne, John, F.R.S.E., F.G.S. 41 Southside-road, Inverness.
1876. *Horne, Robert R. 150 Hope-street, Glasgow.
1875. *Horniman, F. J., F.R.G.S., F.L.S. Surrey Mount, Forest Hill, London, S.E.

Year of
Election.

1884. *Horsfall, Richard. Post Office-buildings, George-street, Halifax.
1856. ‡Horsley, John H. 1 Ormond-terrace, Cheltenham.
1884. *Hotblach, G. S. Prince of Wales-road, Norwich.
1868. ‡Hotson, W. C. Upper King-street, Norwich.
1858. ‡Hounsfield, James. Hemsworth, Pontefract.
1884. ‡Houston, William. Legislative Library, Toronto, Canada.
1883. *Hovenden, Frederick, F.L.S., F.G.S. Glenlea, Thurlow Park-road, West Dulwich, Surrey, S.E.
Hovenden, W. F., M.A. Bath.
1879. *Howard, D. 60 Belsize Park, London, N.W.
1883. §Howard, James Fielden, M.D., M.R.C.S. Randycroft, Shaw.
1882. ‡Howard, William Frederick, Assoc. Memb. Inst. C.E. 13 Cavendish-street, Chesterfield, Derbyshire.
1883. ‡Howarth, Richard. York-road, Birkdale, Southport.
1876. ‡Howatt, James. 146 Buchanan-street, Glasgow.
1885. §Howden, James C., M.D. Sunnyside, Montrose, N.B.
1857. ‡Howell, Henry H., F.G.S., Director of the Geological Survey of Scotland. Geological Survey Office, Victoria-street, Edinburgh.
1868. ‡Howell, Rev. Canon Hinds. Drayton Rectory, near Norwich.
1884. ‡Howland, Edward P., M.D. 211 41½-street, Washington, U.S.A.
1884. ‡Howland, Oliver Aiken. Toronto, Canada.
1865. *Howlett, Rev. Frederick, F.R.A.S. East Tisted Rectory, Alton, Hants.
1863. ‡Howorth, H. H. Derby House, Eccles, Manchester.
1883. ‡Howorth, John, J.P. Springbank, Burnley, Lancashire.
1883. ‡Hoyle, James. Blackburn.
1883. ‡Hoyle, William. Claremont, Bury, Lancashire.
1870. ‡Hubback, Joseph. 1 Brunswick-street, Liverpool.
1835. *Hudson, Henry, M.D., M.R.I.A. Glenville, Fermoy, Co. Cork.
1879. ‡Hudson, Robert S., M.D. Redruth, Cornwall.
1883. ‡Hudson, Rev. W. C. 58 Belmont-street, Southport.
1867. *Hudson, William H. H., M.A., Professor of Mathematics in King's College, London. 14 Geraldine-road, Wandsworth, London, S.W.
1858. *Huggins, William, D.C.L. Oxon., LL.D. Camb., F.R.S., F.R.A.S. Upper Tulse Hill, Brixton, London, S.W.
1857. ‡Huggon, William. 30 Park-row, Leeds.
1883. ‡Hughes, Miss E. P. Newnham College, Cambridge.
1871. *Hughes, George Pringle, J.P. Middleton Hall, Wooler, Northumberland.
1870. *Hughes, Lewis. Fenwick-court, Liverpool.
1876. *Hughes, Rev. Thomas Edward. Wallfield House, Reigate.
1868. §Hughes, T. M'K., M.A., F.G.S., Woodwardian Professor of Geology in the University of Cambridge.
1865. ‡Hughes, W. R., F.L.S., Treasurer of the Borough of Birmingham. Birmingham.
1883. ‡Hulke, John Whitaker, F.R.S., F.R.C.S., F.G.S. 10 Old Burlington-street, London, W.
1867. §Hull, Edward, M.A., LL.D., F.R.S., F.G.S., Director of the Geological Survey of Ireland and Professor of Geology in the Royal College of Science. 14 Hume-street, Dublin.
*Hulse, Sir Edward, Bart., D.C.L. 47 Portland-place, London, W.; and Breamore House, Salisbury.
1884. *Humphreys, A. W. 45 William-street, New York, U.S.A.
1878. ‡Humphreys, H. Castle-square, Carnarvon.
1880. ‡Humphreys, Noel A., F.S.S. Ravenhurst, Hook, Kingston-on-Thames.

Year of Election.

1856. ‡Humphries, David James. 1 Keynsham-parade, Cheltenham.
1862. *HUMPHRY, GEORGE MURRAY, M.D., F.R.S., Professor of Surgery in the University of Cambridge. Grove Lodge, Cambridge.
1877. *HUNT, ARTHUR ROOPE, M.A., F.G.S. Southwood, Torquay.
1865. ‡Hunt, J. P. Gospel Oak Works, Tipton.
1884. ‡HUNT, T. STERRY, M.A., D.Sc., LL.D., F.R.S. 105 Union-avenue, Montreal, Canada.
1864. ‡Hunt, W. 72 Pulteney-street, Bath.
1875. *Hunt, William. The Woodlands, Tyndall's Park, Clifton, Bristol.
1868. ‡Hunter, Christopher. Alliance Insurance Office, North Shields.
1867. ‡Hunter, David. Blackness, Dundee.
1881. ‡Hunter, F. W. 4 Westmoreland-road, Newcastle-on-Tyne.
1881. ‡Hunter, Rev. John. 38 The Mount, York.
1884. *Hunter, Michael, jun. Greystones, Sheffield.
1869. *Hunter, Rev. Robert, LL.D., F.G.S. Forest Retreat, Staples-road, Loughton, Essex.
1879. §HUNTINGTON, A. K., F.C.S., Professor of Metallurgy in King's College, London. King's College, London, W.C.
1885. §Huntly, The Right Hon. the Marquis of. Aboyne Castle, Aberdeenshire.
1863. ‡Huntsman, Benjamin. West Retford Hall, Retford.
1883. *Hurst, Charles Herbert. Owens College, Manchester.
1869. ‡Hurst, George. Bedford.
1882. §Hurst, Walter, B.Sc. West Lodge, Todmorden.
1861. *Hurst, William John. Drumaness Mills, Ballynahinch, Lisburn, Ireland.
1870. ‡Hurter, Dr. Ferdinand. Appleton, Widnes, near Warrington.
Husband, William Dalla. May Bank, Bournemouth.
1882. ‡Hussey, Captain E. R., R.E. 24 Waterloo-place, Southampton.
1876. ‡Hutchinson, John. 22 Hamilton Park-terrace, Glasgow.
1868. *Hutchison, Robert, F.R.S.E. 29 Chester-street, Edinburgh.
Hutton, Crompton. Putney Park, Surrey, S.W.
1864. *Hutton, Darnton. 14 Cumberland-terrace, Regent's Park, London, N.W.
1857. ‡Hutton, Henry D. 17 Palmerston-road, Dublin.
1861. *HUTTON, T. MAXWELL. Summerhill, Dublin.
1852. ‡HUXLEY, THOMAS HENRY, Ph.D., LL.D., D.C.L., F.R.S., F.L.S., F.G.S. 4 Marlborough-place, London, N.W.
Hyde, Edward. Dukinfield, near Manchester.
1883. ‡Hyde, George H. 23 Arbour-street, Southport.
1871. *Hyett, Francis A. Painswick House, Stroud, Gloucestershire.

1882. *I'Anson, James, F.G.S. Fairfield House, Darlington.
1879. ‡Ibbotson, H. J. 26 Collegiate-crescent, Sheffield.
1869. ‡IDDESLEIGH, The Right Hon. the Earl of, G.C.B., D.C.L., F.R.S. Pynes, Exeter.
Ihne, William, Ph.D. Heidelberg.
1873. ‡Ikin, J. I. 19 Park-place, Leeds.
1861. ‡Iles, The Ven. Archdeacon, M.A. The Close, Lichfield.
1884. §Iles, George. Windsor Hotel, Montreal, Canada.
1885. §im-Thurn, Everard F. British Guiana.
1858. ‡Ingham, Henry. Wortley, near Leeds.
1876. ‡Inglis, Anthony. Broomhill, Partick, Glasgow.
1871. ‡INGLIS, The Right Hon. JOHN, D.C.L., LL.D., Lord Justice-General of Scotland. Edinburgh.
1876. ‡Inglis, John, jun. Prince's-terrace, Dowanhill, Glasgow.
1883. ‡Ingram, Rev. D. C. Church-street, Southport.

Year of Election.

1852. ‡INGRAM, J. K., LL.D., M.R.I.A., Librarian to the University of Dublin. 2 Wellington-road, Dublin.
1885. §Ingram, William, M.A. Gamrie, Banff.
1882. ‡Irving, Rev. A., B.A., B.Sc., F.G.S. Wellington College, Wokingham, Berks.
1883. ‡Isherwood, James. 18 York-road, Birkdale, Southport.
1881. ‡Ishiguro, Isoji. Care of the Japanese Legation, 9 Cavendish-square, London, W.

1870. ‡Jack, James. 26 Abercromby-square, Liverpool.
1859. ‡Jack, John, M.A. Belhelvie-by-Whitecairns, Aberdeenshire.
1884. ‡Jack, Peter. People's Bank, Halifax, Nova Scotia, Canada.
1876. *Jack, William, LL.D., Professor of Mathematics in the University of Glasgow. 10 The College, Glasgow.
1883. §JACKSON, A. H. New Bridge-street, Strangeways, Manchester.
1879. ‡Jackson, Arthur, F.R.C.S. Wilkinson-street, Sheffield.
1883. ‡Jackson, Mrs. Esther. 16 East Park-terrace, Southampton.
1883. ‡Jackson, Frank. 11 Park-crescent, Southport.
1883. *Jackson, F. J. Brooklands, Alderley Edge, Manchester.
1883. ‡Jackson, Mrs. F. J. Brooklands, Alderley Edge, Manchester.
1874. *Jackson, Frederick Arthur. Belmont, Lyme Regis, Dorset.
1885. §Jackson, Henry. 19 Golden-square, Aberdeen.
1866. ‡Jackson, H. W., F.R.A.S., F.G.S. 15 The Terrace, High-road, Lewisham, S.E.
1869. §Jackson, Moses. The Vale, Ramsgate.
1863. *Jackson-Gwilt, Mrs. H. Moonbeam Villa, The Grove, New Wimbledon, Surrey.
1874. *Jaffe, John. Edenvale, Strandtown, near Belfast.
1865. *Jaffray, John. Park-grove, Edgbaston, Birmingham.
1872. ‡James, Christopher. 8 Laurence Pountney-hill, London, E.C.
1860. ‡James, Edward H. Woodside, Plymouth.
1863. *JAMES, Sir WALTER, Bart., F.G.S. 6 Whitehall-gardens, London, S.W.
1884. §James, W. Culver, M.D. 11 Marloes-road, London, W.
1858. ‡James, William C. Woodside, Plymouth.
1884. §Jameson, W. C. 48 Baker-street, Portman-square, London, W.
1881. ‡Jamieson, Andrew, Principal of the College of Science and Arts, Glasgow.
1885. §Jamieson, Patrick. Peterhead, N.B.
1885. §Jamieson, Thomas. 140 Union-street, Aberdeen.
1859. *Jamieson, Thomas F., F.G.S. Ellon, Aberdeenshire.
1850. ‡Jardine, Alexander. Jardine Hall, Lockerby, Dumfriesshire.
1870. ‡Jardine, Edward. Beach Lawn, Waterloo, Liverpool.
1853. *Jarratt, Rev. Canon J., M.A. North Cave, near Brough, Yorkshire.
1870. ‡Jarrold, John James. London-street, Norwich.
1856. §JEFFERY, HENRY M., M.A., F.R.S. 9 Dunstanville-terrace, Falmouth.
1855. *Jeffray, John. Cardowan House, Millerston, Glasgow.
1883. ‡Jeffreys, Miss Gwyn. 1 The Terrace, Kensington, London, W.
1867. ‡Jeffreys, Howel, M.A., F.R.A.S. Pump-court, Temple, London, E.C.
1885. §Jeffreys, Dr. Richard Parker. Eastwood House, Chesterfield.
1852. ‡JELLETT, Rev. JOHN H., D.D., M.R.I.A., Provost of Trinity College, Dublin.
1881. §JELLICOE, C. W. A. Southampton.
1864. ‡Jelly, Dr. W. Aveleanas, 11, Valencia, Spain.

Year of Election.

1873. §Jenkins, Major-General J. J. 14 St. James's-square, London, S.W.
1880. *JENKINS, Sir JOHN JONES, M.P. The Grange, Swansea.
Jennette, Matthew. 102A Conway-street, Birkenhead.
1852. ‡Jennings, Francis M., F.G.S., M.R.I.A. Brown-street, Cork.
1872. ‡Jennings, W. 13 Victoria-street, London, S.W.
1878. ‡Jephson, Henry L. Chief Secretary's Office, The Castle, Dublin.
*Jerram, Rev. S. John, M.A. 2 Kent-avenue, Castle Hill, Ealing, Middlesex, W.
1872. ‡*Jesson, Thomas. 7 Upper Wimpole-street, Cavendish-square, London, W.*
Jessop, William, jun. Butterley Hall, Derbyshire.
1884. ‡Jewell, Lieutenant Theo. F. Torpedo Station, Newport, Rhode Island, U.S.A.
1884. ‡Johns, Thomas W. Yarmouth, Nova Scotia, Canada.
1884. §Johnson, Alexander, M.A., LL.D., Professor of Mathematics in McGill College, Montreal. 5 Prince of Wales-terrace, Montreal, Canada.
1883. ‡Johnson, Miss Alice. Llandaff House, Cambridge.
1883. ‡Johnson, Ben. Micklegate, York.
1871. *Johnson, David, F.C.S., F.G.S. 52 Fitzjohn's-avenue, South Hampstead, London, N.W.
1881. ‡Johnson, Major E. Cecil. Junior United Service Club, Charles-street, London, S.W.
1883. ‡Johnson, Edmund Litler. 73 Albert-road, Southport.
Johnson, Edward. 22 Talbot-street, Southport.
1865. *Johnson, G. J. 36 Waterloo-street, Birmingham.
1875. §Johnson, James Henry, F.G.S. 73 Albert-road, Southport.
1866. ‡*Johnson, John G. 18A Basinghall-street, London, E.C.*
1872. ‡Johnson, J. T. 27 Dale-street, Manchester.
1861. ‡Johnson, Richard. 27 Dale-street, Manchester.
1870. ‡Johnson, Richard C., F.R.A.S. 19 Catherine-street, Liverpool.
1863. ‡Johnson, R. S. Hanwell, Fence Houses, Durham.
1881. ‡Johnson, Samuel George. Municipal Offices, Nottingham.
1883. ‡Johnson, W. H. F. Llandaff House, Cambridge.
1883. ‡Johnson, William. Harewood, Roe-lane, Southport.
1861. ‡Johnson, William Beckett. Woodlands Bank, near Altrincham, Cheshire.
1883. ‡Johnston, H. H. Tudor House, Champion Hill, London, S.E.
1859. ‡Johnston, James. Newmill, Elgin, N.B.
1864. ‡Johnston, James. Manor House, Northend, Hampstead, London, N.W.
1884. ‡Johnston, John L. 27 St. Peter-street, Montreal, Canada.
1883. §Johnston, Thomas. Broomsleigh, Seal, Sevenoaks.
1884. ‡Johnston, Walter R. Fort Qu'Appele, N.W. Territory, Canada.
1884. *Johnston, W. H. 11 Chapel-street, Preston.
1885. §Johnston-Lavis, H. J., M.D., F.G.S. Palazzo Caramanico, Chiatomone, Naples.
1864. *Johnstone, James. Alva House, Alva, by Stirling, N.B.
1864. ‡*Johnstone, John. 1 Barnard-villas, Bath.*
1876. ‡Johnstone, William. 5 Woodside-terrace, Glasgow.
1864. ‡Jolly, Thomas. Park View-villas, Bath.
1871. §JOLLY, WILLIAM, F.R.S.E., F.G.S., H.M. Inspector of Schools. St. Andrew's-road, Pollokshields, Glasgow.
1881. ‡Jones, Alfred Orlando, M.D. Belton House, Harrogate.
1849. ‡Jones, Baynham. Selkirk Villa, Cheltenham.
1856. ‡Jones, C. W. 7 Grosvenor-place, Cheltenham.

Year of Election.

1883. §Jones, George Oliver, M.A. 11 Cambridge-road, Waterloo, Liverpool.
1884. §Jones, Rev. Harry, M.A. Bartonmere, Bury St. Edmunds; and Savile Club, Piccadilly, London, W.
1877. ‡Jones, Henry C., F.C.S. Normal School of Science, South Kensington, London, S.W.
1883. ‡Jones, Rev. Canon Herbert. Waterloo, Liverpool.
1881. §Jones, J. Viriamu, M.A., B.Sc., Principal of the University College of South Wales and Monmouthshire. Cardiff.
1873. ‡Jones, Theodore B. 1 Finsbury-circus, London, E.C.
1880. ‡Jones, Thomas. 15 Gower-street, Swansea.
1860. ‡Jones, Thomas Rupert, F.R.S., F.G.S. 10 Uverdale-road, King's-road, Chelsea, London, S.W.
1883. ‡Jones, William. Elsinore, Birkdale, Southport.
1875. *Jose, J. E. 3 Queen-square, Bristol.
1884. ‡Joseph, J. H. 738 Dorchester-street, Montreal, Canada.
1875. *Joule, Benjamin St. John B., J.P. 12 Wardle-road, Sale, near Manchester.
1842. *Joule, James Prescott, LL.D., F.R.S., F.C.S. 12 Wardle-road, Sale, near Manchester.
1847. ‡Jowett, Rev. B., M.A., Regius Professor of Greek in the University of Oxford. Balliol College, Oxford.
1858. ‡Jowett, John. Leeds.
1879. ‡Jowitt, A. Hawthorn Lodge, Clarkehouse-road Sheffield.
1872. ‡Joy, Algernon. Junior United Service Club, St. James's, London, S.W.
1848. *Joy, Rev. Charles Ashfield. Grove Parsonage, Wantage, Berkshire.
1883. §Joyce, Rev. A. G., B.A. St. John's Croft, Winchester.
1848. *Jubb, Abraham. Halifax.
1870. ‡Judd, John Wesley, F.R.S., Sec. G.S., Professor of Geology in the Royal School of Mines. Hurstleigh, Kew.
1883. ‡Justice, Philip M. 14 Southampton-buildings, Chancery-lane, London, W.C.

1868. *Kaines, Joseph, M.A., D.Sc. 8 Osborne-road, Stroud Green-road, London, N.
Kane, Sir Robert, M.D., LL.D., F.R.S., M.R.I.A., F.C.S. Fortlands, Killiney, Co. Dublin.
1857. ‡Kavanagh, James W. Grenville, Rathgar, Ireland.
1859. ‡Kay, David, F.R.G.S. 19 Upper Phillimore-place, Kensington, London, W.
Kay, John Cunliff. Fairfield Hall, near Skipton.
1847. *Kay, Rev. William, D.D. Great Leghs Rectory, Chelmsford.
1883. ‡Kearne, John H. Westcliffe-road, Birkdale, Southport.
1884. ‡Keefer, Samuel. Brockville, Ontario, Canada
1884. §Keefer, Thomas Alexander. Port Arthur, Ontario, Canada.
1875. ‡Keeling, George William. Tuthill, Lydney.
1881. ‡Keeping, Walter, M.A., F.G.S. The Museum, York.
1878. *Kelland, William Henry. 110 Jermyn-street, London, S.W.; and Grettans, Bow, North Devon.
1884. §Kellogg, J. H., M.D. Battle Creek, Michigan, U.S.A.
1876. ‡Kelly, Andrew G. The Manse, Alloa, N.B.
1864. *Kelly, W. M., M.D. 11 The Crescent, Taunton, Somerset.
1885. §Keltie, J. Scott, Librarian R.G.S. 1 Savile-row, London, W.
1853. ‡Kemp, Rev. Henry William, B.A. The Charter House, Hull.
1884. ‡Kemper, Andrew C. 101 Broadway, Cincinnati, U.S.A.
1875. ‡Kennedy, Alexander B. W., M.Inst.C.E., Professor of Engineering in University College, London.

Year of Election.

1884. ‡Kennedy, George L., M.A., F.G.S., Professor of Chemistry and Geology in King's College, Windsor, Nova Scotia, Canada.
1876. ‡Kennedy, Hugh. Redclyffe, Partickhill, Glasgow.
1884. ‡Kennedy, John. 113 University-street, Montreal, Canada.
1884. §Kennedy, William. Hamilton, Ontario, Canada.
Kent, J. C. Levant Lodge, Earl's Croome, Worcester.
1857. *Ker, André Allen Murray. Newbliss House, Newbliss, Ireland.
1855. *Ker, Robert. Dougalston, Milngavie, N.B.
1876. ‡Ker, William. 1 Windsor-terrace West, Glasgow.
1881. ‡Kermode, Philip M. C. Ramsay, Isle of Man.
1884. ‡Kerr, James, M.D. Winnipeg, Canada.
1883. §Kerr, Dr. John. Garscadden House, near Kilpatrick, Glasgow.
1869. *Kesselmeyer, Charles A. 1 Peter-street, Manchester.
1869. *Kesselmeyer, William Johannes. Villa 'Mon Repos,' Altrincham, Cheshire.
1861. *Keymer, John. Parker-street, Manchester.
1883. *Keynes, J. N., M.A., B.Sc., F.S.S. 6 Harvey-road, Cambridge.
1876. ‡Kidston, J. B. West Regent-street, Glasgow.
1876. ‡Kidston, William. Ferniegair, Helensburgh, N.B.
1885. *Kilgour, Alexander. Loirston House, Cove, near Aberdeen.
1865. *Kinahan, Edward Hudson, M.R.I.A. 11 Merrion-square North Dublin.
1878. ‡Kinahan, Edward Hudson, jun. 11 Merrion-square North, Dublin.
1860. ‡KINAHAN, G. HENRY, M.R.I.A. Geological Survey of Ireland, 14 Hume-street, Dublin.
1884. §Kinahan, Gerrard, A. 24 Waterloo-road, Dublin.
1875. *KINCH, EDWARD, F.C.S. Agricultural College, Cirencester.
1872. *King, Mrs. E. M. 34 Cornwall-road, Westbourne Park, London, W.
1875. *King, F. Ambrose. Avonside, Clifton, Bristol.
1883. *King, Francis. Rose Bank, Penrith.
1871. *King, Rev. Herbert Poole. Royal Thames Yacht Club, 7 Albemarle-street, London, W.
1855. ‡King, James. Levernholme, Hurlet, Glasgow.
1883. *King, John Godwin. Welford House, Greenhill, Hampstead, London, N.W.
1870. §King, John Thomson. 4 Clayton-square, Liverpool.
King, Joseph. Welford House, Greenhill, Hampstead, London, N.W.
1883. *King, Joseph, jun. Welford House, Greenhill, Hampstead, London, N.W.
1864. §KING, KELBURNE, M.D. 6 Albion-street, and Royal Institution, Hull.
1860. *King, Mervyn Kersteman. 1 Vittoria-square, Clifton, Bristol.
1875. *King, Percy L. Avonside, Clifton, Bristol.
1870. ‡King, William. 13 Adelaide-terrace, Waterloo, Liverpool.
King, William Poole, F.G.S. Avonside, Clifton, Bristol.
1869. ‡Kingdon, K. Taddiford, Exeter.
1861. ‡Kingsley, John. Ashfield, Victoria Park, Manchester.
1883. ‡Kingston, Mrs. Sarah B. The Limes, Clewer, near Windsor.
1876. §Kingston, Thomas. The Limes, Clewer, near Windsor.
1835. Kingstone, A. John, M.A. Mosstown, Longford, Ireland.
1875. §KINGZETT, CHARLES T., F.C.S. Trevena, Amhurst Park, London, N.
1867. ‡Kinloch, Colonel. Kirriemuir, Logie, Scotland.
1867. *KINNAIRD, The Right Hon. Lord. 2 Pall Mall East, London, S.W.; and Rossie Priory, Inchture, Perthshire.
1870. ‡Kinsman, William R. Branch Bank of England, Liverpool.

Year of Election.

1860. ‡KIRKMAN, Rev. THOMAS P., M.A., F.R.S. Croft Rectory, near Warrington.
Kirkpatrick, Rev. W. B., D.D. 48 North Great George-street, Dublin.
1876. *Kirkwood, Anderson, LL.D., F.R.S.E. 7 Melville-terrace, Stirling, N.B.
1875. ‡Kirsop, John. 6 Queen's-crescent, Glasgow.
1883. ‡Kirsop, Mrs. 6 Queen's-crescent, Glasgow.
1870. ‡Kitchener, Frank E. Newcastle, Staffordshire.
1881. ‡*Kitching, Langley. 50 Caledonian-road, Leeds.*
1869. ‡Knapman, Edward. The Vineyard, Castle-street, Exeter.
1883. §Knight, J. R. 32 Lincoln's Inn-fields, London, W.C.
1872. *Knott, George, LL.B., F.R.A.S. Knowles Lodge, Cuckfield, Hayward's Heath, Sussex.
1873. *Knowles, George. Moorhead, Shipley, Yorkshire.
1872. ‡Knowles, James. The Hollies, Clapham Common, S.W.
1870. ‡Knowles, Rev. J. L. 103 Earl's Court-road, Kensington, London, W.
1874. ‡Knowles, William James. Flixton-place, Ballymena, Co. Antrim.
1883. ‡Knowlys, Rev. C. Hesketh. The Rectory, Roe-lane, Southport.
1883. ‡Knowlys, Mrs. C. Hesketh. The Rectory, Roe-lane, Southport.
1876. ‡*Knox, David N., M.A., M.B. 8 Belgrave-terrace, Hillhead, Glasgow.*
*Knox, George James. 29 Portland-terrace, Regent's Park, London, N.W.
1875. *Knubley, Rev. E. P. Staveley Rectory, Leeds.
1883. ‡Knubley, Mrs. Staveley Rectory, Leeds.
1881. ‡Kurobe, Hiroo. Legation of Japan, 9 Cavendish-square, London, W.
1870. ‡Kynaston, Josiah W., F.C.S. Kensington, Liverpool.
1865. ‡Kynnersley, J. C. S. The Leveretts, Handsworth, Birmingham.
1882. ‡Kyshe, John B. 19 Royal-avenue, Sloane-square, London, S.W.

1858. ‡Lace, Francis John. Stone Gapp, Cross-hill, Leeds.
1884. ‡Laflamme, Rev. Professor J. C. K. Laval University, Quebec, Canada.
1885. *Laing, J. Gerard. 1 Elm-court, Temple, London, E.C.
1870. ‡Laird, H. H. Birkenhead.
1870. §Laird, John. Grosvenor-road, Claughton, Birkenhead.
1882. ‡Lake, G. A. K., M.D. East Park-terrace, Southampton.
1880. ‡Lake, Samuel. Milford Docks, Milford Haven.
1877. ‡Lake, W. C., M.D. Teignmouth.
1859. ‡Lalor, John Joseph, M.R.I.A. City Hall, Cork Hill, Dublin.
1883. §Lamb, W. J. 11 Gloucester-road, Birkdale, Southport.
1883. §LAMBERT, Rev. BROOKE, LL.B. The Vicarage, Greenwich, Kent, S.E.
1884. ‡Lamborn, Robert H. Montreal, Canada.
1884. §Lancaster, Alfred. Manchester-road, Burnley, Lancashire.
1871. ‡Lancaster, Edward. Karesforth Hall, Barnsley, Yorkshire.
1877. ‡*Landon, Frederic George, M.A., F.R.A.S. 8 The Circus, Greenwich, London, S.E.*
1883. ‡Lang, Rev. Gavin. Inverness.
1859. ‡Lang, Rev. John Marshall, D.D. Barony, Glasgow.
1864. ‡*Lang, Robert. Langford Lodge, College-road, Clifton, Bristol.*
1882. ‡*Langstaff, Dr. Bassett, Southampton.*
1870. ‡Langton, Charles. Barkhill, Aigburth, Liverpool.
*Langton, William. Docklands, Ingatestone, Essex.

Year of
Election.

1865. ‡LANKESTER, E. RAY, M.A., LL.D., F.R.S., Professor of Comparative Anatomy and Zoology in University College, London. 11 Wellington Mansions, North Bank, London, N.W.
1880. *LANSDELL, Rev. HENRY, D.D., F.R.A.S., F.R.G.S. Eyre Cottage, The Grove, Blackheath, London, S.E.
Lanyon, Sir Charles. The Abbey, White Abbey, Belfast.
1884. ‡Lanza, Professor G. Massachusetts Institute of Technology, Boston, U.S.A.
1878. ‡Lapper, E., M.D. 61 Harcourt-street, Dublin.
1885. §LAPWORTH, CHARLES, F.G.S., Professor of Geology and Mineralogy in the Mason Science College, Birmingham. 93 Stirling-road, Edgbaston, Birmingham.
1881. ‡Larmor, Joseph, M.A., Professor of Natural Philosophy in Queen's College, Galway.
1883. §Lascelles, B. P. Harrow.
1870. *LATHAM, BALDWIN, M.Inst.C.E., F.G.S. 7 Westminster-chambers, Westminster, S.W.
1870. ‡LAUGHTON, JOHN KNOX, M.A., F.R.A.S., F.R.G.S. Royal Naval College, Greenwich, S.E.
1883. ‡Laurie, Major-General. Oakfield, Nova Scotia.
1870. *Law, Channell. Sydney Villa, 36 Outram-road, Addiscombe, Croydon.
1878. ‡Law, Henry, C.E. 5 Queen Anne's-gate, London, S.W.
1862. ‡Law, Rev. James Edmund, M.A. Little Shelford, Cambridgeshire.
1884. §Law, Robert. Hollingsworth, Walsden, near Todmorden.
1870. ‡Lawrence, Edward. Aigburth, Liverpool.
1881. §Lawrence, Rev. F., B.A. The Vicarage, Westow, York.
1875. ‡Lawson, George, Ph.D., LL.D., Professor of Chemistry and Botany. Halifax, Nova Scotia.
1885. §Lawson, James. 8 Church-street, Huntly, N.B.
1857. ‡Lawson, The Right Hon. James A., LL.D., D.C.L., M.R.I.A. 27 Fitzwilliam-street, Dublin.
1868. **Lawson, M. Alexander, M.A., F.L.S. Botanic Gardens, Oxford.*
1853. ‡Lawton, William. 5 Victoria-terrace, Derringham, Hull.
1865. ‡Lea, Henry. 35 Paradise-street, Birmingham.
1857. ‡Leach, Colonel R. E. Mountjoy, Phœnix Park, Dublin.
1883. *Leach, Charles Catterall. 18 Lord-street, Liverpool.
1883. §Leach, John. Haverhill House, Bolton.
1870. *Leaf, Charles John, F.L.S., F.G.S., F.S.A. Old Change, London, E.C.; and Painshill, Cobham.
1884. *Leahy, John White, J.P. South Hill, Killarney, Ireland.
1884. ‡Learmont, Joseph B. 120 Mackay-street, Montreal, Canada.
1847. *LEATHAM, EDWARD ALDAM, M.P. Whitley Hall, Huddersfield; and 46 Eaton-square, London, S.W.
1863. ‡Leavers, J. W. The Park, Nottingham.
1884. *Leavitt, Erasmus Darwin. 604 Main-street, Cambridgeport, Massachusetts, U.S.A.
1872. ‡LEBOUR, G. A., M.A., F.G.S., Professor of Geology in the College of Physical Science, Newcastle-on-Tyne.
1884. ‡Leckie, R. G. Springhill, Cumberland County, Nova Scotia.
1883. ‡Lee, Daniel W. Halton Bank, Pendleton, near Manchester.
1861. ‡Lee, Henry, M.P. Sedgeley Park, Manchester.
1883. ‡Lee, J. H. Warburton. Rossall, Fleetwood.
1853. *LEE, JOHN EDWARD, F.G.S., F.S.A. Villa Syracusa, Torquay.
1884. *Leech, Bosdin T. Oak Mount, Temperley, Cheshire.
1882. ‡Lees, R. W. Moira-place, Southampton.

Year of Election.

1859. ‡Lees, William, M.A. St. Leonard's, Morningside-place, Edinburgh.
1883. *Leese, Miss H. K. Hazeldene, Fallowfield, Manchester.
*Leese, Joseph. Hazeldene, Fallowfield, Manchester.
1883. ‡Leese, Mrs. Hazeldene, Fallowfield, Manchester.
1881. ‡LE FEUVRE, J. E. Southampton.
1872. ‡LEFEVRE, The Right Hon. G. SHAW, F.R.G.S. 18 Bryanston-square, London, W.
*LEFROY, General Sir JOHN HENRY, R.A., K.C.M.G., C.B., LL.D., F.R.S., F.R.G.S. 82 Queen's-gate, London, S.W.
*Legh, Lieutenant-Colonel George Cornwall. High Legh Hall, Cheshire.
1869. ‡Le Grice, A. J. Trereife, Penzance.
1868. ‡LEICESTER, The Right Hon. the Earl of, K.G. Holkham, Norfolk.
1861. *Leigh, Henry. Moorfield, Swinton, near Manchester.
1856. ‡LEIGH, The Right Hon. Lord, D.C.L. 37 Portman-square, London, W.; and Stoneleigh Abbey, Kenilworth.
1870. ‡Leighton, Andrew. 35 High-park-street, Liverpool.
1880. ‡Leighton, William Henry, F.G.S. 2 Merton-place, Chiswick.
1867. ‡Leishman, James. Gateacre Hall, Liverpool.
1870. ‡Leister, G. F. Gresbourn House, Liverpool.
1859. §Leith, Alexander. Glenkindie, Inverkindie, N.B.
1882. §Lemon, James, M.Inst.C.E. 11 The Avenue, Southampton.
1863. *LENDY, Major AUGUSTE FREDERIC, F.L.S., F.G.S. Sunbury House, Sunbury, Middlesex.
1867. ‡Leng, John. 'Advertiser' Office, Dundee.
1878. ‡Lennon, Rev. Francis. The College, Maynooth, Ireland.
1861. ‡*Lennox, A. C. W. 7 Beaufort-gardens, Brompton, London, S.W.*
Lentaigne, Sir John, C.B., M.D. Tallaght House, Co. Dublin; and 1 Great Denmark-street, Dublin.
Lentaigne, Joseph. 12 Great Denmark-street, Dublin.
1871. ‡LEONARD, HUGH, F.G.S., M.R.I.A., F.R.G.S.I. St. David's, Malahide-road, Co. Dublin.
1874. ‡Lepper, Charles W. Laurel Lodge, Belfast.
1872. ‡Lermit, Rev. Dr. School House, Dedham.
1884. §Lesage, Louis. City Hall, Montreal, Canada.
1871. ‡Leslie, Alexander, M.Inst.C.E. 72 George-street, Edinburgh.
1883. §Lester, Thomas. Fir Bank, Penrith.
1880. ‡LETCHER, R. J. Lansdowne-terrace, Walters-road, Swansea.
1866. §LEVI, Dr. LEONE, F.S.A., F.S.S., F.R.G.S., Professor of Commercial Law in King's College, London. 5 Crown Office-row, Temple, London, E.C.
1879. ‡Lewin, Colonel, F.R.G.S. Garden Corner House, Chelsea Embankment, London, S.W.
1870. ‡LEWIS, ALFRED LIONEL. 35 Colebrooke-row, Islington, London, N.
1884. *Lewis, W. T. The Mardy, Aberdare.
1853. ‡Liddell, George William Moore. Sutton House, near Hull.
1860. ‡LIDDELL, The Very Rev. H. G., D.D., Dean of Christ Church, Oxford.
1876. ‡Lietke, J. O. 30 Gordon-street, Glasgow.
1862. ‡LILFORD, The Right Hon. Lord, F.L.S. Lilford Hall, Oundle, Northamptonshire.
*LIMERICK, The Right Rev. CHARLES GRAVES, Lord Bishop of, D.D., F.R.S., M.R.I.A. The Palace, Henry-street, Limerick.
1883. ‡*Lincoln, Frank. 111 Marylebone-road, London, N.W.*
1878. ‡Lincolne, William. Ely, Cambridgeshire.
1881. *Lindley, William, C.E., F.G.S. 10 Kidbrooke-terrace, Blackheath, London, S.E.

Year of
Election.

*Lindsay, Charles. Ridge Park, Lanark, N.B.
1870. ‡Lindsay, Thomas, F.C.S. Maryfield College, Maryhill, by Glasgow.
1871. ‡Lindsay, Rev. T. M., M.A., D.D. Free Church College, Glasgow.
Lingwood, Robert M., M.A., F.L.S., F.G.S. 1 Derby-villas, Cheltenham.
1876. §Linn, James. Geological Survey Office, India-buildings, Edinburgh.
1883. §Lisle, H. Claud. Nantwich.
1882. *Lister, Rev. Henry, B.A. Hawridge Rectory, Berkhampstead.
1870. §Lister, Thomas. Victoria-crescent, Barnsley, Yorkshire.
1876. ‡Little, Thomas Evelyn. 42 Brunswick-street, Dublin.
Littledale, Harold. Liscard Hall, Cheshire.
1881. ‡Littlewood, Rev. B. C., M.A. Holmdale, Cheltenham.
1861. *Liveing, G. D., M.A., F.R.S., F.C.S., Professor of Chemistry in the University of Cambridge. Cambridge.
1876. *Liversidge, Archibald, F.R.S., F.C.S., F.G.S., F.R.G.S., Professor of Chemistry and Mineralogy in the University of Sydney, N. S.W. (Care of Messrs. Trübner & Co., Ludgate Hill, London, E.C.)
1864. §Livesay, J. G. Cromartie House, Ventnor, Isle of Wight.
1880. ‡Llewelyn, John T. D. Penllegare, Swansea.
Lloyd, Rev. A. R. Hengold, near Oswestry.
1842. Lloyd, Edward. King-street, Manchester.
1865. ‡Lloyd, G. B. Edgbaston-grove, Birmingham.
*Lloyd, George, M.D., F.G.S. Acock's-green, near Birmingham.
1865. ‡Lloyd, John. Queen's College, Birmingham.
Lloyd, Rev. Rees Lewis. Belper, Derbyshire.
1877. *Lloyd, Sampson Samuel. Moor Hall, Sutton Coldfield.
1865. *Lloyd, Wilson, F.R.G.S. Myrod House, Wednesbury.
1854. *Lobley, James Logan, F.G.S., F.R.G.S. 19 Stonebridge Park, Willesden, N.W.
1853. *Locke, John. 133 Leinster-road, Dublin.
1867. *Locke, John. 83 Addison-road, Kensington, London, W.
1863. ‡Lockyer, J. Norman, F.R.S., F.R.A.S. Science Schools, South Kensington, London, S.W.
1875. *Lodge, Oliver J., D.Sc., Professor of Physics in University College, Liverpool. 26 Waverley-road, Sefton Park, Liverpool.
1883. ‡Lofthouse, John. West Bank, Rochdale.
1883. ‡London, Rev. H. High Lee, Knutsford.
1862. ‡Long, Andrew, M.A. King's College, Cambridge.
1876. ‡Long, H. A. Charlotte-street, Glasgow.
1872. ‡Long, Jeremiah. 50 Marine Parade, Brighton.
1871. *Long, John Jex. 727 Duke-street, Glasgow.
1851. ‡Long, William, F.G.S. Hurts Hall, Saxmundham, Suffolk.
1883. *Long, William. Thelwall Heys, near Warrington.
1883. ‡Long, Mrs. Thelwall Heys, near Warrington.
1883. ‡Long, Miss. Thelwall Heys, near Warrington.
1866. §Longdon, Frederick. Osmaston-road, Derby.
1883. ‡Longe, Francis D. Coddenham Lodge, Cheltenham.
1883. ‡Longmaid, William Henry. 4 Rawlinson-road, Southport.
1875. *Longstaff, George Blundell, M.A., M.B., F.C.S., F.S.S. Southfield Grange, Wandsworth, S.W.
1871. §Longstaff, George Dixon, M.D., F.C.S. Butterknowle, Wandsworth, S.W.; and 9 Upper Thames-street, London, E.C.
1872. *Longstaff, Llewellyn Wood, F.R.G.S. Ridgelands, Wimbledon, Surrey.
1881. *Longstaff, Mrs. Ll. W. Ridgelands, Wimbledon, Surrey.
1883. §Longton, E. J., M.D. Lord-street, Southport.
1861. *Lord, Edward. Adamroyd, Todmorden.

Year of Election.

1863. ‡Losh, W. S. Wreay Syke, Carlisle.
1883. *Louis, D. A., F.C.S. Harpenden.
1876. *Love, James, F.R.A.S., F.G.S., F.Z.S. 2 Queensland-terrace, Oval-road, Croydon.
1883. §Love, James Allen. 8 Eastbourne-road West, Southport.
1875. *Lovett, W. Jesse. Alverthorpe-road, Wakefield.
1867. *Low, James F. Monifieth, by Dundee.
1885. §Lowdell, Sydney Poole. Baldwyn's Hill, East Grinstead, Sussex.
1885. §Lowe, Arthur C. W. Gosfield Hall, Halstead, Essex.
1863. *Lowe, Lieut.-Colonel Arthur S. H., F.R.A.S. 76 Lancaster-gate, London, W.
1861. *LOWE, EDWARD JOSEPH, F.R.S., F.R.A.S., F.L.S., F.G.S., F.R.M.S. Shirenewton, near Chepstow.
1884. ‡Lowe, F. J. Elm-court, Temple, London, E.C.
1870. ‡*Lowe, G. C. 67 Cecil-street, Greenheys, Manchester.*
1868. ‡*Lowe, John, M.D. King's Lynn.*
1886. *Lowe, John Lander. 132 Bath-row, Birmingham.
1850. ‡Lowe, William Henry, M.D., F.R.S.E. Balgreen, Slateford, Edinburgh.
1881. ‡Lubbock, Arthur Rolfe. High Elms, Hayes, Kent.
1853. *LUBBOCK, Sir JOHN, Bart., M.P., D.C.L., LL.D., F.R.S., Pres. L.S., F.G.S. 34 Queen Anne's-gate, London, S.W.; and High Elms, Hayes, Kent.
1881. ‡Lubbock, John B. High Elms, Hayes, Kent.
1870. ‡Lubbock, Montague, M.D. 19 Grosvenor-street, London, W.
1878. ‡Lucas, Joseph. Tooting Graveney, London, S.W.
1849. *Luckcock, Howard. Oak-hill, Edgbaston, Birmingham.
1875. §Lucy, W. C., F.G.S. The Winstones, Brookthorpe, Gloucester.
1881. ‡Luden, C. M. 4 Bootham-terrace, York.
1867. *Luis, John Henry. Cidhmore, Dundee.
1873. ‡Lumley, J. Hope Villa, Thornbury, near Bradford, Yorkshire.
1884. ‡*Lumsden, Miss L. J.*
1885. §LUMSDEN, ROBERT. Ferryhill House, Aberdeen.
1866. *Lund, Charles. Ilkley, Yorkshire.
1873. ‡Lund, Joseph. Ilkley, Yorkshire.
1850. *Lundie, Cornelius. Teviot Bank, Newport-road, Cardiff.
1853. ‡Lunn, William Joseph, M.D. 23 Charlotte-street, Hull.
1883. *Lupton, Arnold, M.Inst.C.E., F.G.S., Instructor in Coal Mining in Yorkshire College. 4 Albion-place, Leeds.
1858. *Lupton, Arthur. Headingley, near Leeds.
1874. *LUPTON, SYDNEY, M.A. The Harehills, near Leeds.
1864. *Lutley, John. Brockhampton Park, Worcester.
1871. ‡Lyell, Leonard, F.G.S. 92 Onslow-gardens, London, S.W.
1884. §Lyman, A. Clarence. 84 Victoria-street, Montreal, Canada.
1884. ‡Lyman, H. H. 74 McTavish-street, Montreal, Canada.
1884. ‡Lyman, Roswell C. 74 McTavish-street, Montreal, Canada.
1874. ‡Lynam, James. Ballinasloe, Ireland.
1885. §Lyon, Alexander, jun. 52 Carden-place, Aberdeen.
1857. ‡Lyons, Robert D., M.B., M.R.I.A. 8 Merrion-square West, Dublin.
1878. ‡Lyte, Cecil Maxwell. Cotford, Oakhill-road, Putney, S.W.
1862. *LYTE, F. MAXWELL, F.C.S. Cotford, Oakhill-road, Putney, S.W.

1852. ‡McAdam, Robert. 18 College-square East, Belfast.
1854. *MACADAM, STEVENSON, Ph.D., F.R.S.E., F.C.S., Lecturer on Chemistry. Surgeons' Hall, Edinburgh; and Brighton House, Portobello, by Edinburgh.
1876. *MACADAM, WILLIAM IVISON. Surgeons' Hall, Edinburgh.

Year of Election.

1868. ‡MACALISTER, ALEXANDER, M.D., F.R.S., Professor of Anatomy in the University of Cambridge. Strathmore House, Harvey-road, Cambridge.
1878. §MACALISTER, DONALD, M.A., M.D., B.Sc. St. John's College, Cambridge.
1879. §MacAndrew, James J. Lukesland, Ivybridge, South Devon.
1883. §MacAndrew, Mrs. J. J. Lukesland, Ivybridge, South Devon.
1883. §MacAndrew, William. Westwood House, near Colchester.
1866. *M'Arthur, Alexander, M.P., F.R.G.S. Raleigh Hall, Brixton Rise, London, S.W.
1884. ‡Macarthur, Alexander. Winnipeg, Canada.
1884. ‡Macarthur, D. Winnipeg, Canada.
1840. MACAULAY, JAMES, A.M., M.D. 25 Carlton-road, Maida Vale, London, N.W.
1871. *MacBrayne, Robert. Messrs. Black and Wingate, 5 Exchange-square, Glasgow.
1884. ‡McCabe, T., Chief Examiner of Patents. Patent Office, Ottawa, Canada.
1866. ‡M'CALLAN, Rev. J. F., M.A. Basford, near Nottingham.
1855. ‡M'Cann, Rev. James, D.D., F.G.S. The Lawn, Lower Norwood, Surrey, S.E.
1884. *McCarthy, J. J., M.D. Junior Army and Navy Club, London, S.W.
1884. §McCausland, Orr. Belfast.
1876. *M'CLELLAND, A. S. 4 Crown-gardens, Dowanhill, Glasgow.
1868. ‡M'CLINTOCK, Admiral Sir FRANCIS L., R.N., F.R.S., F.R.G.S. United Service Club, Pall Mall, London, S.W.
1872. *M'Clure, J. H., F.R.G.S. 5 Park-row, Albert-gate, London, S.W.
1874. ‡M'Clure, Sir Thomas, Bart. Belmont, Belfast.
1878. *M'Comas, Henry. Homestead, Dundrum, Co. Dublin.
1859. *M'Connell, David C., F.G.S. Care of Mr. H. K. Lewis, 136 Gower-street, London, W.C.
1858. ‡M'Connell, J. E. Woodlands, Great Missenden.
1883. ‡McCrossan, James. 29 Albert-road, Southport.
1876. ‡M'Culloch, Richard. 109 Douglas-street, Blythswood-square, Glasgow.
1884. ‡MACDONALD, The Right Hon. Sir JOHN ALEXANDER, G.C.B., D.C.L., LL.D. Ottawa, Canada.
1884. ‡MacDonald, Kenneth. Town Hall, Inverness.
1884. *McDonald, W. C. 891 Sherbrooke-street, Montreal, Canada.
1878. ‡McDonnell, Alexander. St. John's, Island Bridge, Dublin.
1884. §MacDonnell, Mrs. F. H. 1433 St. Catherine-street, Montreal, Canada.
MacDonnell, Hercules H. G. 2 Kildare-place, Dublin.
1883. ‡MacDonnell, Rev. Canon J. C., D.D. Maplewell, Loughborough.
1878. ‡McDonnell, James. 32 Upper Fitzwilliam-street, Dublin.
1878. ‡McDonnell, Robert, M.D., F.R.S., M.R.I.A. 89 Merrion-square West, Dublin.
1884. ‡Macdougall, Alan. Toronto, Canada.
1884. ‡McDougall, John. 35 St. François Xavier-street, Montreal, Canada.
1878. *M'Ewan, John. 4 Douglas-terrace, Stirling, N.B.
1881. ‡Macfarlane, Alexander, D.Sc., F.R.S.E., Professor of Physics in the University of Texas. Austin, Texas, U.S.A.
1871. ‡M'Farlane, Donald. The College Laboratory, Glasgow.
1885. §Macfarlane, J. M., D.Sc. 3 Bellevue-terrace, Edinburgh.
1855. *Macfarlane, Walter. 22 Park-circus, Glasgow.
1879. ‡Macfarlane, Walter, jun. 12 Lynedoch-crescent, Glasgow.
1884. ‡Macfie, K. N., B.A., B.C.L. Winnipeg, Canada.
1854. *Macfie, Robert Andrew. Dreghorn, Colinton, Edinburgh.

Year of Election.

1867. *M'Gavin, Robert. Ballumbie, Dundee.
1855. ‡MacGeorge, Andrew, jun. 21 St. Vincent-place, Glasgow.
1872. ‡M'George, Mungo. Nithsdale, Laurie Park, Sydenham, S.E.
1884. ‡MacGillivray, James. 42 Catchurt-street, Montreal, Canada.
1884. ‡MacGoun, Archibald, jun., B.A., B.C.L. 19 Place d'Armes, Montreal, Canada.
1873. ‡McGowen, William Thomas. Oak-avenue, Oak Mount, Bradford, Yorkshire.
1885. §Macgregor, Alexander, M.D. 256 Union-street, Aberdeen.
1884. *MacGregor, James Gordon, M.A., D.Sc., F.R.S.E., Professor of Physics in Dalhousie College, Halifax, Nova Scotia, Canada.
1885. §M'Gregor-Robertson, J., M.A., M.B. 400 Great Western-road, Glasgow.
1876. ‡M'Grigor, Alexander B., LL.D. 19 Woodside-terrace, Glasgow.
1874. ‡MacIlwaine, Rev. Canon, D.D., M.R.I.A. Ulsterville, Belfast.
1867. *M'Intosh, W. C., M.D., LL.D., F.R.S. L. & E., F.L.S., Professor of Natural History in the University of St. Andrews. 2 Abbotsford-crescent, St. Andrews, N.B.
1884. ‡McIntyre, John, M.D. Odiham, Hants.
1854. *MacIver, Charles. 8 Abercromby-square, Liverpool.
1883. ‡Mack, Isaac A. Trinity-road, Bootle.
1884. §Mackay, Alexander Howard. The Academy, Picton, Nova Scotia, Canada.
1885. §Mackay, John Yule, M.D. The University, Glasgow.
1873. ‡McKendrick, John G., M.D., F.R.S. L. & E., Professor of Physiology in the University of Glasgow. The University, Glasgow.
1883. §McKendrick, Mrs. The University, Glasgow.
1880. *Mackenzie, Colin. Junior Athenæum Club, Piccadilly, London, W.
1885. §Mackenzie, J. T. Glenmuick, Ballater, N.B.
1884. §McKenzie, Stephen, M.D. 26 Finsbury-circus, London, E.C.
1884. ‡McKenzie, Thomas, B.A. School of Science, Toronto, Canada.
1883. §Mackeson, Henry. Hythe, Kent.
1865. ‡Mackeson, Henry B., F.G.S. Hythe, Kent.
1872. *Mackey, J. A. 1 Westbourne-terrace, Hyde Park, London, W.
1867. ‡Mackie, Samuel Joseph. 17 Howley-place, London, W.
1884. ‡McKilligan, John B. 387 Main-street, Winnipeg, Canada.
1867. *Mackinlay, David. 6 Great Western-terrace, Hillhead, Glasgow.
1865. ‡Mackintosh, Daniel, F.G.S. 32 Glover-street, Birkenhead.
1884. §Mackintosh, James B. New York, U.S.A.
1850. ‡Macknight, Alexander. 20 Albany-street, Edinburgh.
1867. ‡Mackson, H. G. 25 Cliff-road, Woodhouse, Leeds.
1872. *McLachlan, Robert, F.R.S., F.L.S. West View, Clarendon-road, Lewisham, S.E.
1873. ‡McLandsborough, John, M.Inst.C.E., F.R.A.S., F.G.S. Manningham, Bradford, Yorkshire.
1885. *M'Laren, The Right Hon. Lord, F.R.S.E. 46 Moray-place, Edinburgh.
1860. ‡Maclaren, Archibald. Summertown, Oxfordshire.
1864. ‡MacLaren, Duncan. Newington House, Edinburgh.
1873. ‡MacLaren, Walter S. B. Newington House, Edinburgh.
1882. ‡Maclean, Inspector-General, C.B. 1 Rockstone-terrace, Southampton.
1884. ‡McLennan, Frank. 317 Drummond-street, Montreal, Canada.
1884. ‡McLennan, Hugh. 317 Drummond-street, Montreal, Canada.
1884. ‡McLennan, John. Lancaster, Ontario, Canada.
1862. ‡Macleod, Henry Dunning. 17 Gloucester-terrace, Campden Hill-road, London, W.

Year of Election.

1868. §M'Leod, Herbert, F.R.S., F.C.S., Professor of Chemistry in the Royal Indian Civil Engineering College, Cooper's Hill, Egham.
1875. ‡Macliver, D. 1 Broad-street, Bristol.
1875. ‡Macliver, P. S. 1 Broad-street, Bristol.
1861. *Maclure, John William, F.R.G.S., F.S.S. Whalley Range, Manchester.
1883. *McMahon, Colonel C. A. 20 Nevern-square, South Kensington, London, S.W.
1883. ‡MacMahon, Captain P. A., R.A., Instructor in Mathematics at the Royal Military Academy, Woolwich.
1878. *M'Master, George, M.A., J.P. Donnybrook, Ireland.
1862. ‡Macmillan, Alexander. Streatham-lane, Upper Tooting, Surrey, S.W.
1884. *Macmillan, Angus, M.D. Hull.
1874. ‡MacMordie, Hans, M.A. 8 Donegall-street, Belfast.
1884. ‡McMurrick, Playfair. Ontario Agricultural College, Guelph, Ontario, Canada.
1871. ‡M'Nab, William Ramsay, M.D., Professor of Botany in the Royal College of Science, Dublin. 4 Vernon-parade, Clontarf, Dublin.
1870. ‡*Macnaught, John, M.D. 74 Huskisson-street, Liverpool.*
1867. ‡M'Neill, John. Balhousie House, Perth.
1883. ‡McNicoll, Dr. E. D. 15 Manchester-road, Southport.
1878. ‡Macnie, George. 59 Bolton-street, Dublin.
1883. ‡Macpherson, J. 44 Frederick-street, Edinburgh.
*Macrory, Edmund, M.A. 2 Ilchester-gardens, Prince's-square, London, W.
1876. *Mactear, James. 16 Burnbank-gardens, Glasgow.
1855. ‡Macvicar, Rev. John Gibson, D.D., LL.D. Moffat, N.B.
1883. §McWhirter, William. 170 Kent-road, Glasgow.
1883. §Madden, W. H. Marlborough College, Wilts.
1883. §Maggs, Thomas Charles, F.G.S. Yeovil.
1868. ‡Magnay, F. A. Drayton, near Norwich.
1875. *Magnus, Philip. 48 Gloucester-place, Portman-square, London, W.
1878. ‡Mahony, W. A. 34 College-green, Dublin.
1869. ‡Main, Robert. Admiralty, Whitehall, London, S.W.
1885. *Maitland, Sir James R. G., Bart. Stirling, N.B.
1883. §Maitland, P. C. 233 East India-road, London, E.
*Malcolm, Frederick. Morden College, Blackheath, London, S.E.
1881. ‡Malcolm, Lieut.-Colonel, R.E. 72 Nunthorpe-road, York.
1874. ‡Malcolmson, A. B. Friends' Institute, Belfast.
1857. ‡Mallet, John William, Ph.D., M.D., F.R.S., F.C.S., Professor of Chemistry in the University of Virginia, U.S.A.
1870. ‡Manifold, W. H. 45 Rodney-street, Liverpool.
1884. *Mann, F. S. W. Linton Park, Maidstone.
1885. §Mann, George. 72 Bon Accord-street, Aberdeen.
1866. §Mann, Robert James, M.D., F.R.A.S. 5 Kingsdown-villas, Wandsworth Common, S.W.
Manning, His Eminence Cardinal. Archbishop's House, Westminster, S.W.
1878. §Manning, Robert. 4 Upper Ely-place, Dublin.
1864. ‡Mansel-Pleydell, J. C. Whatcombe, Blandford.
1870. ‡Marcoartu, Senor Don Arturo de. Madrid.
1883. ‡Marginson, James Fleetwood. The Mount, Fleetwood, Lancashire.
1864. ‡Markham, Clements R., C.B., F.R.S., F.L.S., Sec.R.G.S., F.S.A. 21 Eccleston-square, London, S.W.
1863. ‡Marley, John. Mining Office, Darlington.

Year of Election.

1881. *Marr, John Edward, B.A., F.G.S. St. John's College, Cambridge.
1871. ‡Marreco, A. Friere-. College of Physical Science, Newcastle-on-Tyne.
1857. ‡Marriott, William, F.C.S. Grafton-street, Huddersfield.
1842. Marsden, Richard. Norfolk-street, Manchester.
1884. *Marsden, Samuel. St. Louis, Missouri, U.S.A.
1883. *Marsh, Henry. Cressy House, Woodsley-road, Leeds.
1870. ‡Marsh, John. Rann Lea, Rainhill, Liverpool.
1864. ‡Marsh, Thomas Edward Miller. 37 Grosvenor-place, Bath.
1882. *Marshall, A. Milnes, M.A., M.D., D.Sc., F.R.S., Professor of Zoology in Owens College, Manchester.
1881. ‡Marshall, D. H. Greenhill Cottage, Rothesay.
1881. *Marshall, John, F.R.A.S., F.G.S. Church Institute, Leeds.
1881. §Marshall, John Ingham Fearby. 28 St. Saviourgate, York.
1876. ‡Marshall, Peter. 6 Parkgrove-terrace, Glasgow.
1858. ‡Marshall, Reginald Dykes. Adel, near Leeds.
1849. *Marshall, William P., M.Inst.C.E. 15 Augustus-road, Birmingham.
1865. §Marten, Edward Bindon. Pedmore, near Stourbridge.
1883. ‡Marten, Henry John. 4 Storey's-gate, London, S.W.
1848. ‡Martin, Henry D. 4 Imperial-circus, Cheltenham.
1878. ‡Martin, Professor H. Newell, F.R.S. John Hopkins University, Baltimore, U.S.A.
1883. *Martin, John Biddulph, M.A., F.S.S. 17 Hyde Park-gate, London, S.W.
1884. §Martin, N. H., F.L.S. 29 Moseley-street, Newcastle-on-Tyne.
1836. Martin, Studley. Liverpool.
*Martineau, Rev. James, LL.D., D.D. 35 Gordon-square, London, W.C.
1865. ‡Martineau, R. F. Highfield-road, Edgbaston, Birmingham.
1865. ‡Martineau, Thomas. 7 Cannon-street, Birmingham.
1875. ‡Martyn, Samuel, M.D. 8 Buckingham-villas, Clifton, Bristol.
1883. §Marwick, James, LL.D. Killermont, Maryhill, Glasgow.
1878. ‡Masaki, Taiso. Japanese Consulate, 84 Bishopsgate-street Within, London, E.C.
1847. ‡Maskelyne, Nevil Story, M.A., M.P., F.R.S., F.G.S., Professor of Mineralogy in the University of Oxford. 39 Cornwall-gardens, London, W.
1861. *Mason, Hugh, M.P. Groby Hall, Ashton-under-Lyne.
1879. ‡Mason, James, M.D. Montgomery House, Sheffield.
1868. ‡Mason, James Wood, F.G.S. The Indian Museum, Calcutta. (Care of Messrs. Henry S. King & Co., 65 Cornhill, London, E.C.)
1876. §Mason, Robert. 6 Albion-crescent, Dowanhill, Glasgow.
1876. ‡Mason, Stephen. 9 Rosslyn-terrace, Hillhead, Glasgow.
Massey, Hugh, Lord. Hermitage, Castleconnel, Co. Limerick.
1885. §Masson, Orme, D.Sc. 58 Great King-street, Edinburgh.
1883. ‡Mather, Robert V. Birkdale Lodge, Birkdale, Southport.
1865. *Mathews, G. S. 32 Augustus-road, Edgbaston, Birmingham.
1861. *Mathews, William, M.A., F.G.S. 60 Harborne-road, Birmingham.
1881. ‡Mathwin, Henry, B.A. Bickerton House, Southport.
1883. ‡Mathwin, Mrs. 40 York-road, Birkdale, Southport.
1865. ‡Matthews, C. E. Waterloo-street, Birmingham.
1858. ‡Matthews, F. C. Mandre Works, Driffield, Yorkshire.
1885. §Matthews, James. Springhill, Aberdeen.
1885. §Matthews, J. Duncan. Springhill, Aberdeen.

Year of
Election.

1863. ‡Maughan, Rev. W. Benwell Parsonage, Newcastle-on-Tyne.
1865. *MAW, GEORGE, F.L.S., F.G.S., F.S.A. Benthall Hall, Broseley, Shropshire.
1876. ‡Maxton, John. 6 Belgrave-terrace, Glasgow.
1864. *Maxwell, Francis. 4 Moray-place, Edinburgh.
*Maxwell, Robert Perceval. Finnebrogue, Downpatrick.
1883. §May, William, F.G.S., F.R.G.S. Northfield, St. Mary Cray, Kent.
1883. ‡Mayall, George. Clairville, Birkdale, Southport.
1868. ‡Mayall, J. E., F.C.S. Stork's Nest, Lancing, Sussex.
1884. *Maybury, A. C., D.Sc. 19 Bloomsbury-square, London, W.C.
1835. Mayne, Edward Ellis. Rocklands, Stillorgan, Ireland.
1878. *Mayne, Thomas. 33 Castle-street, Dublin.
1863. ‡Mease, George D. Lydney, Gloucestershire.
1878. §Meath, The Most Rev. C. P. Reichel, D.D., Bishop of. Meath.
1884. ‡Mecham, Arthur. 11 Newton-terrace, Glasgow.
1883. ‡*Medd, John Charles, M.A. 99 Park-street, Grosvenor-square, London, W.*
1881. ‡Meek, Sir James. Middlethorpe, York.
1871. ‡Meikie, James, F.S.S. 6 St. Andrew's-square, Edinburgh.
1879. §Meiklejohn, John W. S., M.D. 105 Holland-road, London, W.
1881. *MELDOLA, RAPHAEL, F.R.A.S., F.C.S., F.I.C., Professor of Chemistry in the City and Guilds of London Institute, Finsbury Technical Institute. 21 John-street, Bedford-row, London, W.C.
1867. ‡MELDRUM, CHARLES, M.A., F.R.S., F.R.A.S. Port Louis, Mauritius.
1883. ‡Mellis, Rev. James. 23 Park-street, Southport.
1879. *Mellish, Henry. Hodsock Priory, Worksop.
1866. ‡MELLO, Rev. J. M., M.A., F.G.S. St. Thomas's Rectory, Brampton, Chesterfield.
1883. §Mello, Mrs. J. M. St. Thomas's Rectory, Brampton, Chesterfield.
1854. ‡Melly, Charles Pierre. 11 Rumford-street, Liverpool.
1881. §Melrose, James. Clifton, York.
1847. ‡Melville, Professor Alexander Gordon, M.D. Queen's College, Galway.
1863. ‡Melvin, Alexander. 42 Buccleuch-place, Edinburgh.
1877. *Menabrea, General Count, LL.D. 14 Rue de l'Elysée, Paris.
1862. ‡MENNELL, HENRY J. St. Dunstan's-buildings, Great Tower-street, London, E.C.
1879. ‡Merivale, John Herman, Professor of Mining in the College of Science, Newcastle-on-Tyne.
1879. ‡Merivale, Walter. Engineers' Office, North-Eastern Railway, Newcastle-on-Tyne.
1877. ‡Merrifield, John, Ph.D., F.R.A.S. Gascoigne-place, Plymouth.
1880. ‡Merry, Alfred S. Bryn Heulog, Sketty, near Swansea.
1872. *Messent, John. 429 Strand, London, W.C.
1863. ‡Messent, P. T. 4 Northumberland-terrace, Tynemouth.
1869. ‡MIALL, LOUIS C., F.G.S., Professor of Biology in Yorkshire College, Leeds.
1865. ‡Middlemore, William. Edgbaston, Birmingham.
1881. *Middlesbrough, The Right Rev. Richard Lacy, D.D., Bishop of. Middlesbrough.
1883. §Middleton, Henry. St. John's College, Cambridge.
1881. §Middleton, R. Morton, F.L.S., F.Z.S. Hudworth Cottage, Castle Eden, Co. Durham.
1876. *Middleton, Robert T., M.P. 197 West George-street, Glasgow.
1881. §MILES, MORRIS. 44 Carlton-road, Southampton.

Year of Election.

1885. §Mill, Hugh Robert, B.Sc., F.R.S.E., F.C.S. Scottish Marine Station, Granton, Edinburgh.
1859. ‡Millar, John, J.P. Lisburn, Ireland.
1863. ‡Millar, John, M.D., F.L.S., F.G.S. Bethnal House, Cambridge-road, London, E.
Millar, Thomas, M.A., LL.D., F.R.S.E. Perth.
1876. ‡Millar, William. Highfield House, Dennistoun, Glasgow.
1876. ‡Millar, W. J. 145 Hill-street, Garnethill, Glasgow.
1882. §Miller, A. J. High-street, Southampton.
1876. ‡Miller, Daniel. 258 St. George's-road, Glasgow.
1875. ‡Miller, George. Brentry, near Bristol.
1884. §Miller, Mrs. Hugh. 51 Lauriston-place, Edinburgh.
1885. §Miller, John. 9 Rubislaw-terrace, Aberdeen.
1861. *Miller, Robert. Cranage Hall, Holmes Chapel, Cheshire.
1876. *Miller, Robert. 1 Lily Bank-terrace, Hillhead, Glasgow.
1884. *Miller, Robert Kalley, M.A., Professor of Mathematics in the Royal Naval College, Greenwich, London, S.E.
1884. ‡Miller, T. F., B.Ap.Sc. Napanee, Ontario, Canada.
1876. ‡Miller, Thomas Paterson. Cairns, Cambuslang, N.B.
1868. *Mills, Edmund J., D.Sc., F.R.S., F.C.S., Young Professor of Technical Chemistry in Anderson's College, Glasgow. 60 John-street, Glasgow.
1880. ‡Mills, Mansfeldt H. Tapton-grove, Chesterfield.
Milne, Admiral Sir Alexander, Bart., G.C.B., F.R.S.E. 13 New-street, Spring-gardens, London, S.W.
1885. §Milne, Alexander D. 40 Albyn-place, Aberdeen.
1882. *Milne, John, F.G.S., Professor of Geology in the Imperial College of Engineering, Tokio, Japan. 13 Clyde-road, Croydon, Surrey.
1885. §Milne, William. 40 Albyn-place, Aberdeen.
1867. *Milne-Home, David, M.A., LL.D., F.R.S.E., F.G.S. 10 York-place, Edinburgh.
1882. §Milnes, Alfred, M.A., F.S.S. 30 Almeric-road, London, S.W.
1880. §Minchin, G. M., M.A. Royal Indian Engineering College, Cooper's Hill, Surrey.
1865. ‡Minton, Samuel, F.G.S. Oakham House, near Dudley.
1855. ‡Mirrlees, James Buchanan. 45 Scotland-street, Glasgow.
1859. ‡Mitchell, Alexander, M.D. Old Rain, Aberdeen.
1876. ‡Mitchell, Andrew. 20 Woodside-place, Glasgow.
1883. ‡Mitchell, Charles T., M.A. 41 Addison-gardens North, Kensington, London, W.
1883. ‡Mitchell, Mrs. Charles T. 41 Addison-gardens North, Kensington, London, W.
1863. ‡Mitchell, C. Walker. Newcastle-on-Tyne.
1873. ‡Mitchell, Henry. Parkfield House, Bradford, Yorkshire.
1885. §Mitchell, Rev. J. Mitford, B.A. 6 Queen's-terrace, Aberdeen.
1870. §Mitchell, John, J.P. York House, Clitheroe, Lancashire.
1868. ‡Mitchell, John, jun. Pole Park House, Dundee.
1885. §Mitchell, P. Chalmers. Christ Church, Oxford.
1879. ‡Mivart, St. George, M.D., F.R.S., F.L.S., F.Z.S., Professor of Biology in University College, Kensington. 71 Seymour-street, London, W.
1884. §Moat, Robert. Spring Grove, Bewdley.
1885. §Moffat, William. 7 Union-place, Aberdeen.
1864. ‡Mogg, John Rees. High Littleton House, near Bristol.
1885. §Moir, James. 25 Carden-place, Aberdeen.
1861. ‡Molesworth, Rev. W. Nassau, M.A. Spotland, Rochdale.
1883. §Mollison, W. L. Clare College, Cambridge.

Year of
Election.

1878. §Molloy, Constantine. 65 Lower Leeson-street, Dublin.
1877. *Molloy, Rev. Gerald, D.D. 86 Stephen's-green, Dublin.
1884. §Monaghan, Patrick. Halifax (Box 379), Nova Scotia, Canada.
1853. ‡Monroe, Henry, M.D. 10 North-street, Sculcoates, Hull.
1882. *Montagu, Samuel, M.P. 12 Kensington Palace-gardens, London, W.
1872. ‡Montgomery, R. Mortimer. 3 Porchester-place, Edgware-road, London, W.
1872. ‡Moon, W., LL.D. 104 Queen's-road, Brighton.
1884. §Moore, George Frederick. 25 Marlborough-road, Tue Brook, Liverpool.
1881. §Moore, Henry. 4 Sheffield-terrace, Kensington, London, W.
*Moore, John Carrick, M.A., F.R.S., F.G.S. 113 Eaton-square, London, S.W.; and Corswall, Wigtonshire.
1866. *Moore, Thomas, F.L.S. Botanic Gardens, Chelsea, London, S.W.
1854. ‡Moore, Thomas John, Cor. M.Z.S. Free Public Museum, Liverpool.
1877. ‡Moore, W. F. The Friary, Plymouth.
1857. *Moore, Rev. William Prior. The Royal School, Cavan, Ireland.
1877. ‡Moore, William Vanderkemp. 15 Princess-square, Plymouth.
1871. ‡More, Alexander G., F.L.S., M.R.I.A. 3 Botanic View, Glasnevin, Dublin.
1881. ‡Morgan, Alfred. 50 West Bay-street, Jacksonville, Florida, U.S.A.
1873. ‡Morgan, Edward Delmar. 15 Rowland-gardens, London, W.
1885. §Morgan, John. 57 Thomson-street, Aberdeen.
1882. §Morgan, Thomas. Cross House, Southampton.
1878. ‡Morgan, William, Ph.D., F.C.S. Swansea.
1867. ‡Morison, William R. Dundee.
1883. §Morley, Henry Forster, M.A., B.Sc., F.C.S. University Hall, Gordon-square, London, W.C.
1863. ‡Morley, Samuel, M.P. 18 Wood-street, Cheapside, London, E.C.
1881. ‡Morrell, W. W. York City and County Bank, York.
1880. ‡Morris, Alfred Arthur Vennor. Wernolau, Cross Inn R.S.O., Carmarthenshire.
1883. ‡Morris, C. S. Millbrook Iron Works, Landore, South Wales.
*Morris, Rev. Francis Orpen, B.A. Nunburnholme Rectory, Hayton, York.
1883. ‡Morris, George Lockwood. Millbrook Iron Works, Swansea.
1880. §Morris, James. 6 Windsor-street, Uplands, Swansea.
1883. ‡Morris, John. 40 Wellesley-road, Liverpool.
1880. ‡Morris, M. I. E. The Lodge, Penclawdd, near Swansea.
Morris, Samuel, M.R.D.S. Fortview, Clontarf, near Dublin.
1876. ‡Morris, Rev. S. S. O., M.A., R.N., F.C.S. H.M.S. 'Garnet,' S. Coast of America.
1874. ‡Morrison, G. J., M.Inst.C.E. 5 Victoria-street, Westminster, S.W.
1871. *Morrison, James Darsie. 27 Grange-road, Edinburgh.
1865. §Mortimer, J. R. St. John's-villas, Driffield.
1869. ‡Mortimer, William. Bedford-circus, Exeter.
1857. §Morton, George H., F.G.S. 122 London-road, Liverpool.
1858. *Morton, Henry Joseph. 2 Westbourne-villas, Scarborough.
1871. ‡Morton, Hugh. Belvedere House, Trinity, Edinburgh.
1868. ‡Moseley, H. N., M.A., LL.D., F.R.S., Linacre Professor of Human and Comparative Anatomy in the University of Oxford. 14 St. Giles's, Oxford.
1883. ‡Moseley, Mrs. 14 St. Giles's, Oxford.

Year of Election.

Mosley, Sir Oswald, Bart., D.C.L. Rolleston Hall, Burton-upon-Trent, Staffordshire.
Moss, John. Otterspool, near Liverpool.
1878. *Moss, John Francis, F.R.G.S. Beechwood, Brincliffe, Sheffield.
1870. ‡Moss, John Miles, M.A. 2 Esplanade, Waterloo, Liverpool.
1876. §Moss, Richard Jackson, F.C.S., M.R.I.A. St. Aubin's, Ballybrack, Co. Dublin.
1873. *Mosse, George Staley. 13 Scarsdale-villas, Kensington, London, W.
1864. *Mosse, J. R. Conservative Club, London, S.W.
1873. ‡Mossman, William. Woodhall, Calverley, Leeds.
1869. §Mott, Albert J., F.G.S. Crickley Hill, Gloucester.
1865. ‡Mott, Charles Grey. The Park, Birkenhead.
1866. §Mott, Frederick T., F.R.G.S. Birstall Hill, Leicester.
1862. *Mouat, Frederick John, M.D., Local Government Inspector. 12 Durham-villas, Campden Hill, London, W.
1856. ‡Mould, Rev. J. G., B.D. Fulmodeston Rectory, Dereham, Norfolk.
1878. *Moulton, J. Fletcher, M.A., M.P., F.R.S. 74 Onslow-gardens, London, S.W.
1863. ‡Mounsey, Edward. Sunderland.
Mounsey, John. Sunderland.
1861. *Mountcastle, William Robert. Bridge Farm, Ellenbrook, near Manchester.
1877. ‡Mount-Edgcumbe, The Right Hon. the Earl of, D.C.L. Mount-Edgcumbe, Devonport.
1882. ‡Mount-Temple, The Right Hon. Lord. Broadlands, Romsey, Hants.
Mowbray, James. Combus, Clackmannan, Scotland.
1850. ‡Mowbray, John T. 15 Albany-street, Edinburgh.
1884. ‡Moyse, C. E., B.A., Professor of English Language and Literature in McGill College, Montreal. 802 Sherbrooke-street, Montreal, Canada.
1884. ‡Moyse, Charles E. 802 Sherbrooke-street, Montreal, Canada.
1876. *Muir, John. 6 Park-gardens, Glasgow.
1874. ‡Muir, M. M. Pattison, M.A. F.R.S.E. Caius College, Cambridge.
1876. §Muir, Thomas, M.A., LL.D., F.R.S.E. Beechcroft, Bishopton, Renfrewshire.
1884. *Muir, William Ker. Detroit, Michigan, U.S.A.
1872. ‡Muirhead, Alexander, D.Sc., F.C.S. 3 Elm-court, Temple, London, E.C.
1871. *Muirhead, Henry, M.D. Bushy Hill, Cambuslang, Lanarkshire.
1876. *Muirhead, Robert Franklin, M.A., B.Sc. Meikle Cloak, Lochwinnoch, Renfrewshire.
1884. §Muirhead-Paterson, Miss Mary. Laurieville, Queen's Drive, Crosshill, Glasgow.
1883. §Mulhall, Michael G. 19 Albion-street, Hyde-park, London, W.
1883. §Mulhall, Mrs. Marion. 19 Albion-street, Hyde-park, London, W.
1884. *Müller, Hugo, Ph.D., F.R.S., F.C.S. 13 Park-square East, Regent's Park, London, N.W.
1880. §Muller, Hugo M. 1 Grünanger-gasse, Vienna.
Munby, Arthur Joseph. 6 Fig-tree-court, Temple, London, E.C.
1866. ‡Mundella, The Right Hon. A. J., M.P., F.R.S., F.R.G.S. The Park, Nottingham.
1876. ‡Munro, Donald, F.C.S. The University, Glasgow.
1885. §Munro, J. E. Crawford, LL.D., Professor of Political Economy in Owens College, Manchester.
1883. *Munro, Robert. Braehead House, Kilmarnock, N.B.
1872. *Munster, H. Sillwood Lodge, Brighton.
1864. ‡Murch, Jerom. Cranwells, Bath.

Year of Election.

1864. *Murchison, K. R. Brockhurst, East Grinstead.
1855. ‡Murdoch, James B. Hamilton-place, Langside, Glasgow.
1852. ‡Murney, Henry, M.D. 10 Chichester-street, Belfast.
1852. ‡Murphy, Joseph John. Old Forge, Dunmurry, Co. Antrim.
1884. ‡Murphy, Patrick. Newry, Ireland.
1869. ‡Murray, Adam. Westbourne Sussex-gardens, Hyde-park, London, W.
Murray, John, F.G.S., F.R.G.S. 50 Albemarle-street, London, W.; and Newsted, Wimbledon, Surrey.
1859. ‡Murray, John, M.D. Forres, Scotland.
*Murray, John, M.Inst.C.E. Downlands, Sutton, Surrey.
1884. §Murray, John. *Challenger* Expedition Office, Edinburgh.
1884. ‡Murray, J. Clark, LL.D., Professor of Logic and Mental and Moral Philosophy in McGill College, Montreal. 111 McKay-street, Montreal, Canada.
1872. ‡Murray, J. Jardine, F.R.C.S.E. 99 Montpellier-road, Brighton.
1863. ‡Murray, William. 34 Clayton-street, Newcastle-on-Tyne.
1883. ‡Murray, W. Vaughan. 4 Westbourne-crescent, Hyde Park, London, W.
1874. §Musgrave, James, J.P. Drumglass House, Belfast.
1861. ‡Musgrove, John, jun. Bolton.
1870. *Muspratt, Edward Knowles. Seaforth Hall, near Liverpool.
1859. §MYLNE, ROBERT WILLIAM, F.R.S., F.G.S., F.S.A. 7 Whitehall-place, London, S.W.

1842. Nadin, Joseph. Manchester.
1876. ‡Napier, James S. 9 Woodside-place, Glasgow.
1876. ‡*Napier, John. Saughfield House, Hillhead, Glasgow.*
1876. *Napier, Captain Johnstone, C.E. Laverstock House, Salisbury.
1872. ‡Nares, Captain Sir G. S., K.C.B., R.N., F.R.S., F.R.G.S. 23 St. Philip's-road, Surbiton.
1850. *NASMYTH, JAMES. Penshurst, Tunbridge.
1883. *Neild, Theodore. Dalton Hall, Manchester.
1873. ‡Neill, Alexander Renton. Fieldhead House, Bradford, Yorkshire.
1873. ‡Neill, Archibald. Fieldhead House, Bradford, Yorkshire.
Neilson, Robert, J.P., D.L. Halewood, Liverpool.
1855. ‡Neilson, Walter. 172 West George-street, Glasgow.
1876. ‡Nelson, D. M. 11 Bothwell-street, Glasgow.
1868. ‡Nevill, Rev. H. R. The Close, Norwich.
1866. *Nevill, The Right Rev. Samuel Tarratt, D.D., F.L.S., Bishop of Dunedin, New Zealand.
1857. ‡Neville, John, M.R.I.A. Roden-place, Dundalk, Ireland.
1852. ‡NEVILLE, PARKE, M.Inst.C.E., M.R.I.A. 58 Pembroke-road, Dublin.
1869. ‡Nevins, John Birkbeck, M.D. 3 Abercromby-square, Liverpool.
1842. New, Herbert. Evesham, Worcestershire.
Newall, Henry. Hare Hill, Littleborough, Lancashire.
*Newall, Robert Stirling, F.R.S., F.R.A.S. Ferndene, Gateshead-upon-Tyne.
1879. ‡Newbould, John. Sharrow Bank, Sheffield.
1866. *Newdigate, Albert L. Engineer's Office, The Harbour, Dover.
1876. ‡*Newhaus, Albert. 1 Prince's-terrace, Glasgow.*
1883. ‡*Newman, Albert Robert. 33 Lisson-grove, Marylebone-road, London, N.W.*
1842. *NEWMAN, Professor FRANCIS WILLIAM. 15 Arundel-crescent, Weston-super-Mare.
1860. *NEWTON, ALFRED, M.A., F.R.S., F.L.S., Professor of Zoology and Comparative Anatomy in the University of Cambridge. Magdalene College, Cambridge.

Year of Election.

1883. ‡Newton, A. W. 7A Westcliffe-road, Birkdale, Southport.
1872. ‡Newton, Rev. J. 125 Eastern-road, Brighton.
1865. ‡*Newton, Thomas Henry Goodwin. Clopton House, near Stratford-on-Avon.*
1883. ‡Nias, Miss Isabel. 56 Montagu-square, London, W.
1882. ‡Nias, J. B., B.A. 56 Montagu-square, London, W.
1867. ‡Nicholl, Thomas. Dundee.
1875. ‡Nicholls, J. F. City Library, Bristol.
1866. ‡NICHOLSON, Sir CHARLES, Bart., M.D., D.C.L., LL.D., F.G.S., F.R.G.S. The Grange, Totteridge, Herts.
1838. *Nicholson, Cornelius, F.G.S., F.S.A. Ashleigh, Ventnor, Isle of Wight.
1871. §Nicholson, E. Chambers. Herne Hill, London, S.E.
1867. ‡NICHOLSON, HENRY ALLEYNE, M.D., D.Sc., F.G.S., Professor of Natural History in the University of Aberdeen.
1884. §Nicholson, Joseph S., M.A., Professor of Political Economy in the University of Edinburgh. 15 Jordan-lane, Edinburgh.
1883. ‡Nicholson, Richard, J.P. Whinfield, Hesketh Park, Southport.
1881. §Nicholson, William R. Clifton, York.
1885. §Nicol, W. W. J., Ph.D. Mason Science College, Birmingham.
1878. ‡Niven, Charles, M.A., F.R.S., F.R.A.S., Professor of Natural Philosophy in the University of Aberdeen. Aberdeen.
1877. ‡Niven, James, M.A. King's College, Aberdeen.
1874. ‡Nixon, Randal C. J., M.A. Royal Academical Institution, Belfast.
1884. ‡Nixon, T. Alcock. 33 Harcourt-street, Dublin.
1863. *NOBLE, Captain ANDREW, C.B., F.R.S., F.R.A.S., F.C.S. Elswick Works, Newcastle-on-Tyne.
1880. ‡Noble, John. Rossenstein, Thornhill-road, Croydon, Surrey.
1879. ‡Noble, T. S., F.G.S. Lendal, York.
1870. ‡Nolan, Joseph, M.R.I.A. 14 Hume-street, Dublin.
1882. §Norfolk, F. Elm Villa, Ordnance-road, Southampton.
1859. ‡Norfolk, Richard. Ladygate, Beverley.
1868. ‡Norgate, William. Newmarket-road, Norwich.
1863. §NORMAN, Rev. ALFRED MERLE, M.A., D.C.L., F.L.S. Burnmoor Rectory, Fence House, Co. Durham.
Norreys, Sir Denham Jephson, Bart. Mallow Castle, Co. Cork.
1865. ‡NORRIS, RICHARD, M.D. 2 Walsall-road, Birchfield, Birmingham.
1872. ‡Norris, Thomas George. Gorphwysfa, Llanrwst, North Wales.
1883. *Norris, William G. Coalbrookdale, Shropshire.
1881. §North, Samuel William, M.R.C.S., F.G.S. 84 Micklegate, York.
1881. ‡North, William, B.A., F.C.S. 28 Regent's Park-road, London, N.W.
*NORTHWICK, The Right Hon. Lord, M.A. 7 Park-street, Grosvenor-square, London, W.
NORTON, The Right Hon. Lord, K.C.M.G. 35 Eaton-place, London, S.W.; and Hamshall, Birmingham.
1868. ‡Norwich, The Hon. and Right Rev. J. T. Pelham, D.D., Lord Bishop of. Norwich.
1861. ‡Noton, Thomas. Priory House, Oldham.
Nowell, John. Farnley Wood, near Huddersfield.
1878. ‡*Nugent, Edward. Seel's-buildings, Liverpool.*
1883. ‡Nunnerley, John. 46 Alexandra-road, Southport.
1883. ‡Nutt, Alfred. Rosendale Hall, West Dulwich, London, S.E.
1883. §Nutt, Miss Lilian. Rosendale Hall, West Dulwich, London, S.E.
1883. §Nutt, Miss Mabel. Rosendale Hall, West Dulwich, London, S.E.

1882. §Obach, Eugene, Ph.D. 2 Victoria-road, Old Charlton, Kent.

Year of Election.

1878. ‡O'Brien, Murrough. 1 Willow-terrace, Blackrock, Co. Dublin.
O'Callaghan, George. Tallas, Co. Clare.
1878. ‡*O'Carroll, Joseph F. 78 Rathgar-road, Dublin.*
1878. ‡O'Conor Don, The, M.P. Clonalis, Castlerea, Ireland.
1883. ‡Odgers, William Blake, M.A., LL.D. 4 Elm-court, Temple, London, E.C.
1858. *Odling, William, M.B., F.R.S., F.C.S., Waynflete Professor of Chemistry in the University of Oxford. 15 Norham-gardens, Oxford.
1884. ‡Odlum, Edward, M.A. Pembroke, Ontario, Canada.
1857. ‡O'Donnavan, William John. 54 Kenilworth-square, Rathgar, Dublin.
1877. §Ogden, Joseph. 21 Station-road, South Norwood, London, S.E.
1885. §Ogilvie, Alexander, LL.D. Gordon's College, Aberdeen.
1876. ‡Ogilvie, Campbell P. Sizewell House, Leiston, Suffolk.
1885. §Ogilvie, F. Grant, M.A., B.Sc. Gordon's College, Aberdeen.
1874. ‡*Ogilvie, Thomas Robertson. Bank Top, 3 Lyle-street, Greenock, N.B.*
*Ogilvie-Forbes, George, M.D., Professor of the Institutes of Medicine in Marischal College, Aberdeen. Boyndlie, Fraserburgh, N.B.
1859. ‡Ogilvy, Rev. C. W. Norman. Baldovan House, Dundee.
1863. ‡Ogilvy, Sir John, Bart. Inverquharity, N.B.
*Ogle, William, M.D., M.A. The Elms, Derby.
1837. ‡O'Hagan, John, M.A., Q.C. 22 Upper Fitzwilliam-street, Dublin.
1884. §O'Halloran, J. S., F.R.G.S. Royal Colonial Institute, Northumberland-avenue, London, W.C.
1881. ‡Oldfield, Joseph. Lendal, York.
1853. ‡Oldham, James, M.Inst.C.E. Cottingham, near Hull.
1885. §Oldham, John. River Plate Telegraph Company, Monte Video.
1863. ‡Oliver, Daniel, F.R.S., F.L.S., Professor of Botany in University College, London. Royal Gardens, Kew, Surrey.
1883. ‡Oliver, J. A. Westwood. Braehead House, Lochwinnoch, Scotland.
1883. §Oliver, Samuel A. Springfield, Wigan, Lancashire.
1882. §Olsen, O. T., F.R.A.S., F.R.G.S. 3 St. Andrew's-terrace, Grimsby.
*Ommanney, Admiral Sir Erasmus, C.B., F.R.S., F.R.A.S., F.R.G.S. The Towers, Yarmouth, Isle of Wight.
1880. *Ommanney, Rev. E. A. 123 Vassal-road, Brixton, London, S.W.
1872. ‡Onslow, D. Robert. New University Club, St. James's, London, S.W.
1883. ‡Oppert, Gustav, Professor of Sanskrit. Madras.
1867. ‡Orchar, James G. 9 William-street, Forebank, Dundee.
1883. §Ord, Miss Maria. Fern Lea, Park-crescent, Southport.
1883. §Ord, Miss Sarah. Fern Lea, Park-crescent, Southport.
1880. ‡O'Reilly, J. P., Professor of Mining and Mineralogy in the Royal College of Science, Dublin.
1842. Ormerod, George Wareing, M.A., F.G.S. Woodway, Teignmouth.
1861. ‡Ormerod, Henry Mere. Clarence-street, Manchester; and 11 Woodland-terrace, Cheetham Hill, Manchester.
1858. ‡Ormerod, T. T. Brighouse, near Halifax.
1835. Orpen, John H., LL.D., M.R.I.A. 58 Stephen's-green, Dublin.
1883. §Orpen, Miss. 58 Stephen's-green, Dublin.
1884. *Orpen, Captain R. T., R.E. 58 Stephen's-green, Dublin.
1884. *Orpen, Rev. T. H., M.A. Plas Dinas, Newnham, Cambridge.
1838. Orr, Alexander Smith. 57 Upper Sackville-street, Dublin.

Year of Election.

1873. ‡Osborn, George. 47 Kingscross-street, Halifax.
1865. ‡Osborne, E. C. Carpenter-road, Edgbaston, Birmingham.
*Osler, A. Follett, F.R.S. South Bank, Edgbaston, Birmingham.
1865. *Osler, Henry F. 50 Carpenter-road, Edgbaston, Birmingham.
1869. *Osler, Sidney F. Chesham Lodge, Lower Norwood, Surrey, S.E.
1884. ‡Osler, William, M.D., Professor of the Institutes of Medicine in McGill College, Montreal, Canada.
1884. §O'Sullivan, James, F.C.S. 71 Spring Terrace-road, Burton-on-Trent.
1882. *Oswald, T. R. New Place House, Southampton.
1881. *Ottewell, Alfred D. 83 Siddals-road, Derby.
1882. ‡*Owen, Rev. C. M., M.A. Woolston Vicarage, Southampton.*
1870. ‡Owen, Harold. The Brook Villa, Liverpool.
Owen, Sir Richard, K.C.B., M.D., D.C.L., LL.D., F.R.S., F.L.S., F.G.S., Hon. F.R.S.E. Sheen Lodge, Mortlake, Surrey, S.W.
1884. §Owen, Professor Richard, M.D., LL.D. New Harmony, Indiana, U.S.A.
1877. ‡Oxland, Dr. Robert, F.C.S. 8 Portland-square, Plymouth.

1883. ‡Page, George W. Fakenham, Norfolk.
1883. ‡Page, Joseph Edward. 12 Saunders-street, Southport.
1872. *Paget, Joseph. Stuffynwood Hall, Mansfield, Nottingham.
1884. ‡Paine, Cyrus F. Rochester, New York, U.S.A.
1875. ‡Paine, William Henry, M.D., F.G.S. Stroud, Gloucestershire.
1870. *Palgrave, R. H. Inglis, F.R.S., F.S.S. Belton, Great Yarmouth.
1883. ‡Palgrave, Mrs. R. H. Inglis. Belton, Great Yarmouth.
1873. ‡Palmer, George, M.P. The Acacias, Reading, Berks.
1878. *Palmer, Joseph Edward. Lyons Mills, Straffan Station, Dublin.
1866. §Palmer, William. Kilbourne House, Cavendish Hill, Sherwood, Notts.
1872. *Palmer, W. R. 1 The Cloisters, Temple, E.C.
Palmes, Rev. William Lindsay, M.A. Naburn Hall, York.
1883. §Pant, F. J. van der. Clifton Lodge, Kingston-on-Thames.
1884. ‡Panton, Professor J. Hoyes, M.D. Guelph College, Ontario, Canada.
1883. ‡Park, Henry. Wigan.
1883. ‡Park, Mrs. Wigan.
1880. *Parke, George Henry, F.L.S., F.G.S. Barrow-in-Furness, Lancashire.
1863. ‡Parker, Henry. Low Elswick, Newcastle-on-Tyne.
1863. ‡Parker, Rev. Henry. Idlerton Rectory, Low Elswick, Newcastle-on-Tyne.
1874. ‡Parker, Henry R., LL.D. Methodist College, Belfast.
Parker, Richard. Dunscombe, Cork.
1865. **Parker, Walter Mantel. High-street, Alton, Hants.*
1853. ‡Parker, William. Thornton-le-Moor, Lincolnshire.
1865. *Parkes, Samuel Hickling, F.L.S. 6 St. Mary's-row, Birmingham.
1864. ‡Parkes, William. 23 Abingdon-street, Westminster, S.W.
1879. §Parkin, William, F.S.S. The Mount, Sheffield.
1859. ‡Parkinson, Robert, Ph.D. West View, Toller-lane, Bradford, Yorkshire.
1841. Parnell, Edward A., F.C.S. Ashley Villa, Swansea.
1862. *Parnell, John, M.A. 1 The Common, Upper Clapton, London, E.
Parnell, Richard, M.D., F.R.S.E. Gattonside Villa, Melrose, N.B.
1883. ‡Parson, T. Cooke, M.R.C.S. Atherston House, Clifton, Bristol.
1877. ‡Parson, T. Edgcumbe. 36 Torrington-place, Plymouth.
1865. *Parsons, Charles Thomas. Norfolk-road, Edgbaston, Birmingham.
1878. ‡Parsons, Hon. C. A. 10 Connaught-place, London, W.

Year of
Election.

1878. ‡Parsons, Hon. and Rev. R. C. 10 Connaught-place, London, W.
1883. ‡Part, C. T. 5 King's Bench-walk, Temple, London, E.C.
1883. ‡Part, Isabella. Rudleth, Watford, Herts.
1875. ‡Pass, Alfred C. Rushmere House, Durdham Down, Bristol.
1881. ‡Patchitt, Edward Cheshire. 128 Derby-road, Nottingham.
1884. *Paton, David. Johnstone, Scotland.
1883. §Paton, Henry, M.A. 15 Myrtle-terrace, Edinburgh.
1884. *Paton, Hugh. 992 Sherbrooke-street, Montreal, Canada.
1883. ‡Paton, Rev. William. Mossfield House, New Ferry, Chester.
1861. ‡Patterson, Andrew. Deaf and Dumb School, Old Trafford, Manchester.
1871. *Patterson, A. Henry. 3 New-square, Lincoln's Inn, London, W.C.
1884. ‡Patterson, Edward Mortimer. Fredericton, New Brunswick, Canada.
1863. ‡Patterson, H. L. Scott's House, near Newcastle-on-Tyne.
1867. ‡Patterson, James. Kinnettles, Dundee.
1876. ‡Patterson, T. L. Belmont, Margaret-street, Greenock.
1874. ‡Patterson, W. H., M.R.I.A. 26 High-street, Belfast.
1863. ‡Pattinson, John, F.C.S. 75 The Side, Newcastle-on-Tyne.
1863. ‡Pattinson, William. Felling, near Newcastle-upon-Tyne.
1867. §Pattison, Samuel Rowles, F.G.S. 50 Lombard-street, London, E.C.
1864. ‡Pattison, Dr. T. H. London-street, Edinburgh.
1879. *Patzer, F. R. Stoke-on-Trent.
1863. ‡Paul, Benjamin H., Ph.D. 1 Victoria-street, Westminster, S.W.
1883. §Paul, G., F.G.S. Moortown, Leeds.
1863. ‡Pavy, Frederick William, M.D., F.R.S. 35 Grosvenor-street, London, W.
1864. ‡Payne, Edward Turner. 3 Sydney-place, Bath.
1881. ‡Payne, J. Buxton. 15 Mosley-street, Newcastle-on-Tyne.
1877. *Payne, J. C. Charles. Botanic-avenue, The Plains, Belfast.
1881. ‡Payne, Mrs. Botanic-avenue, The Plains, Belfast.
1866. ‡Payne, Dr. Joseph F. 78 Wimpole-street, London, W.
1876. ‡Peace, G. H. Monton Grange, Eccles, near Manchester.
1879. ‡Peace, William K. Western Bank, Sheffield.
1885. §Peach, B. N., F.R.S.E., F.G.S. Geological Survey Office, Edinburgh.
1883. ‡Peacock, Ebenezer. 8 Mandeville-place, Manchester-square, London, W.
1875. ‡Peacock, Thomas Francis. 12 South-square, Gray's Inn, London, W.C.
1881. *Pearce, Horace, F.L.S., F.G.S. The Limes, Stourbridge.
1882. §Pearce, Walter, M.B., B.Sc., F.C.S. St. Mary's Hospital, Paddington, London, W.; and Craufurd, Ray Mead, Maidenhead.
1884. ‡Pearce, William. Winnipeg, Canada.
1876. ‡Pearce, W. Elmpark House, Govan, Glasgow.
1881. ‡Pearse, Richard Seward. Southampton.
1883. ‡Pearson, Arthur A. Colonial Office, London, S.W.
1883. §Pearson, Miss Helen E. 69 Alexandra-road, Southport.
1881. ‡Pearson, John. Glentworth House, The Mount, York.
1883. §Pearson, Mrs. Glentworth House, The Mount, York.
1872. *Pearson, Joseph. Grove Farm, Merlin, Raleigh, Ontario, Canada.
1881. ‡Pearson, Richard. 23 Bootham, York.
1870. ‡Pearson, Rev. Samuel. 48 Prince's-road, Liverpool.
1883. *Pearson, Thomas H. Golborne Park, near Newton-le-Willows, Lancashire.
1863. §Pease, H. F. Brinkburn, Darlington.
1863. ‡Pease, Sir Joseph W., Bart., M.P. Hutton Hall, near Guisborough.

Year of Election.

1863. ‡Pease, J. W. Newcastle-on-Tyne.
1883. ‡Peck, John Henry. 52 Hoghton-street, Southport.
Peckitt, Henry. Carlton Husthwaite, Thirsk, Yorkshire.
1855. *Peckover, Alexander, F.S.A., F.L.S., F.R.G.S. Bank House, Wisbech, Cambridgeshire.
*Peckover, Algernon, F.L.S. Sibald's Holme, Wisbech, Cambridgeshire.
1885. §Peddie, W. Spring Valley Villa, Morningside-road, Edinburgh.
1884. ‡Peebles, W. E. 9 North Frederick-street, Dublin.
1883. ‡Peek, C. E. Conservative Club, London, S.W.
1878. *Peek, William. 54 Woodstock-road, Bedford Park, Chiswick, London, W.
*Peel, George. Soho Iron Works, Manchester.
1873. ‡Peel, Thomas. 9 Hampton-place, Bradford, Yorkshire.
1881. ‡Peggs, J. Wallace. 21 Queen Anne's-gate, London, S.W.
1884. §Pegler, Alfred. Maybush Lodge, Old Shirley, Southampton.
1861. *Peile, George, jun. Shotley Bridge, Co. Durham.
1861. *Peiser, John. Barnfield House, 491 Oxford-street, Manchester.
1878. ‡Pemberton, Charles Seaton. 44 Lincoln's Inn-fields, London, W.C.
1865. ‡Pemberton, Oliver. 18 Temple-row, Birmingham.
1861. *Pender, John, M.P. 18 Arlington-street, London, S.W.
1856. §PENGELLY, WILLIAM, F.R.S., F.G.S. Lamorna, Torquay.
1881. ‡Penty, W. G. Melbourne-street, York.
1875. ‡Percival, Rev. John, M.A., LL.D., President of Trinity College, Oxford.
1845. ‡PERCY, JOHN, M.D., F.R.S., F.G.S., 1 Gloucester-crescent, Hyde Park, London, W.
*Perigal, Frederick. Thatched House Club, St. James's-street, London, S.W.
1868. *PERKIN, WILLIAM HENRY, Ph.D., F.R.S., F.C.S. The Chestnuts, Sudbury, Harrow.
1884. ‡Perkin, William Henry, jun., Ph.D. The Chestnuts, Sudbury, Harrow, Middlesex.
1877. ‡Perkins, Loftus. Seaford-street, Regent-square, London, W.C.
1864. *Perkins, V. R. Wotton-under-Edge, Gloucestershire.
1885. §Perrin, Miss Emily. 31 St. John's Wood Park, London, N.W.
Perry, The Right Rev. Charles, M.A., D.D. 32 Avenue-road, Regent's Park, London, N.W.
1879. ‡Perry, James. Roscommon.
1874. *PERRY, JOHN, F.R.S., Professor of Engineering and Applied Mathematics in the Technical College, Finsbury. 10 Penywern-road, South Kensington, London, S.W.
1883. ‡Perry, Ottley L., F.R.G.S. Bolton-le-Moors, Lancashire.
1883. ‡Perry, Russell R. 34 Duke-street, Brighton.
1870. *PERRY, Rev. S. J., F.R.S., F.R.A.S., F.R.M.S. Stonyhurst College Observatory, Whalley, Blackburn.
1885. §Peter, Rev. James. Manse of Deer, Mintlaw, N.B.
1883. §Petrie, Miss Anne S. Stone Hill, Rochdale.
1883. ‡Petrie, Miss Isabella. Stone Hill, Rochdale.
Peyton, Abel. Oakhurst, Edgbaston, Birmingham.
1871. *Peyton, John E. H., F.R.A.S., F.G.S. 108 Marina, St. Leonard's-on-Sea.
1882. ‡Pfoundes, Charles, F.R.G.S. Spring Gardens, London, S.W.
1884. §Phelps, Charles Edgar. Carisbrooke House, The Park, Nottingham.
1884. §Phelps, Mrs. Carisbrooke House, The Park, Nottingham.
1863. *PHENÉ, JOHN SAMUEL, LL.D., F.S.A., F.G.S., F.R.G.S. 5 Carlton-terrace, Oakley-street, London, S.W.

Year of Election.

1870. ‡Philip, T. D. 51 South Castle-street, Liverpool.
1853. *Philips, Rev. Edward. Hollington, Uttoxeter, Staffordshire.
1853. *Philips, Herbert. The Oak House, Macclesfield.
Philips, Robert N., M.P. The Park, Manchester.
1877. §Philips, T. Wishart. 53 Tredegar-square, Bow, London, E.
1863. ‡Philipson, Dr. 1 Savile-row, Newcastle-on-Tyne.
1883. ‡Phillips, Arthur G. 20 Canning-street, Liverpool.
1862. ‡Phillips, Rev. George, D.D. Queen's College, Cambridge.
1872. ‡PHILLIPS, J. ARTHUR, F.R.S., F.G.S., F.C.S., M.Inst.C.E. 18 Fopstone-road, Earl's Court-road, London, S.W.
1880. §Phillips, John H., Hon. Sec. Philosophical and Archæological Society, Scarborough.
1883. ‡Phillips, Mrs. Leah R. 1 East Park-terrace, Southampton.
1883. ‡Phillips, S. Rees. Wanford House, Exeter.
1881. ‡Phillips, William. 9 Bootham-terrace, York.
1868. ‡Phipson, R. M., F.S.A. Surrey-street, Norwich.
1868. ‡PHIPSON, T. L., Ph.D., F.C.S. 4 The Cedars, Putney, Surrey, S.W.
1884. *Pickard, Rev. H. Adair, M.A. 5 Canterbury-road, Oxford.
1883. *Pickard, Joseph William. Oak Bank, Lancaster.
1885. *Pickering, Spencer U. Westfield House, Weston, Bath.
1864. ‡Pickering, William. Oak View, Clevedon.
1884. *Pickett, Thomas E., M.D. Mayville, Kentucky, U.S.A.
1870. ‡Picton, J. Allanson, F.S.A. Sandyknowe, Wavertree, Liverpool.
1871. ‡Pigot, Thomas F., M.R.I.A. Royal College of Science, Dublin.
*Pike, Ebenezer. Besborough, Cork.
1884. ‡Pike, L. G., M.A., F.Z.S. 4 The Grove, Highgate, London, N.
1865. ‡PIKE, L. OWEN. 201 Maida-vale, London, W.
1873. ‡Pike, W. H. University College, Toronto, Canada.
1857. ‡Pilkington, Henry M., LL.D., Q.C. 45 Upper Mount-street, Dublin.
1883. §Pilling, R. C. The Robin's Nest, Blackburn.
1863. *PIM, Admiral BEDFORD C. T., R.N., F.R.G.S. Leaside, Kingswood-road, Upper Norwood, London, S.E.
Pim, George, M.R.I.A. Brenanstown, Cabinteely, Co. Dublin.
1877. ‡Pim, Joseph T. Greenbank, Monkstown, Co. Dublin.
1884. §Pinart, A. G. N. L. 74 Market-street, San Francisco, U.S.A.
1868. ‡Pinder, T. R. St. Andrew's, Norwich.
1876. ‡PIRIE, Rev. G., M.A., Professor of Mathematics in the University of Aberdeen. 33 College Bounds, Old Aberdeen.
1884. ‡Pirz, Anthony. Long Island, New York, U.S.A.
1875. ‡Pitman, John. Redcliff Hill, Bristol.
1883. §Pitt, George Newton, M.A., M.D. 34 Ashburn-place, South Kensington, London, S.W.
1864. ‡Pitt, R. 5 Widcomb-terrace, Bath.
1883. §Pitt, Sydney. 34 Ashburn-place, South Kensington, London, W.
1868. ‡PITT-RIVERS, Major-General A. H. L., F.R.S., F.G.S., F.R.G.S., F.S.A. 4 Grosvenor-gardens, London, S.W.
1872. ‡Plant, Mrs. H. W. 28 Evington-street, Leicester.
1869. §PLANT, JAMES, F.G.S. 40 West-terrace, West-street, Leicester.
1842. PLAYFAIR, The Right Hon. Sir LYON, K.C.B., Ph.D., LL.D., M.P., F.R.S. L. & E., F.C.S. (PRESIDENT.) 68 Onslow-gardens, South Kensington, London, S.W.
1867. ‡PLAYFAIR, Lieut.-Colonel R. L., H.M. Consul, Algeria. (Messrs. King & Co., Pall Mall, London, S.W.)
1884. *Playfair, W. S., M.D., LL.D., Professor of Midwifery in King's College, London. 31 George-street, Hanover-square, London, W.

Year of Election.

1883. *Plimpton, R. T., M.D. 23 Lansdowne-road, Clapham-road, London, S.W.

1857. ‡Plunkett, Thomas. Ballybrophy House, Borris-in-Ossory, Ireland.

1861. *POCHIN, HENRY DAVIS, F.C.S. Bodnant Hall, near Conway.

1881. §Pocklington, Henry. 20 Park-row, Leeds.

1846. ‡POLE, WILLIAM, Mus.Doc., F.R.S., M.Inst.C.E. Athenæum Club, Pall Mall, London, S.W.

*Pollexfen, Rev. John Hutton, M.A. Middleton Tyas Vicarage, Richmond, Yorkshire.

Pollock, A. 52 Upper Sackville-street, Dublin.

1862. *Polwhele, Thomas Roxburgh, M.A., F.G.S. Polwhele, Truro, Cornwall.

1854. ‡Poole, Braithwaite. Birkenhead.

1868. ‡PORTAL, WYNDHAM S. Malshanger, Basingstoke.

1883. *Porter, Rev. C. T., LL.D. Kensington House, Southport.

1874. ‡Porter, Rev. J. Leslie, D.D., LL.D., President of Queen's College, Belfast.

1866. §Porter, Robert. Montpelier Cottage, Beeston, Nottingham.

1883. ‡Postgate, Professor J. P., M.A. Trinity College, Cambridge.

1863. ‡Potter, D. M. Cramlington, near Newcastle-on-Tyne.

1883. ‡Potter, M. C., B.A. St. Peter's College, Cambridge.

Potter, Richard, M.A. 10 Brookside, Cambridge.

1883. §Potts, John. 33 Chester-road, Macclesfield.

1857. *POUNDEN, Captain LONSDALE, F.R.G.S. Junior United Service Club, St. James's-square, London, S.W.; and Brownswood House, Enniscorthy, Co. Wexford.

1873. *Powell, Francis S., M.P., F.R.G.S. Horton Old Hall, Yorkshire; and 1 Cambridge-square, London, W.

1883. §Powell, John. Wannarlwydd House, near Swansea.

1875. ‡Powell, William Augustus Frederick. Norland House, Clifton, Bristol.

1867. ‡Powrie, James. Reswallie, Forfar.

1855. *Poynter, John E. Clyde Neuk, Uddingston, Scotland.

1883. ‡Poynting, J. H., M.A., Professor of Physics in the Mason College, Birmingham. 385 Hagley-road, Edgbaston, Birmingham.

1884. §Prance, Courtenay C. Hatherley Court, Cheltenham.

1884. *Prankerd, A. A., M.A., B.C.L., Law Lecturer in the University of Oxford. Trinity College, Oxford.

1869. *PREECE, WILLIAM HENRY, F.R.S., M.Inst.C.E. Gothic Lodge, Wimbledon Common, Surrey.

1884. *Premio-Real, His Excellency the Count of. Quebec, Canada.

1881. ‡Preston, Rev. Thomas Arthur, M.A. The Green, Marlborough.

*PRESTWICH, JOSEPH, M.A., F.R.S., F.G.S., F.C.S., Professor of Geology in the University of Oxford. 35 St. Giles's, Oxford; and Shoreham, near Sevenoaks.

1884. *Prevost, Major L. de T. 2nd Battalion Argyll and Sutherland Highlanders.

1871. ‡Price, Astley Paston. 47 Lincoln's-Inn-fields, London, W.C.

1856. *PRICE, Rev. BARTHOLOMEW, M.A., F.R.S., F.R.A.S., Sedleian Professor of Natural Philosophy in the University of Oxford, 11 St. Giles's, Oxford.

1872. ‡Price, David S., Ph.D. 26 Great George-street, Westminster, S.W.

1882. ‡Price, John E., F.S.A. 60 Albion-road, Stoke Newington, London, N.

Price, J. T. Neath Abbey, Glamorganshire.

1881. §Price, Peter. Crockherbtown, Cardiff.

Year of Election.

1875. *Price, Rees. 1 Montague-place, Glasgow.
1875. *Price, William Philip. Tibberton Court, Gloucester.
1876. ‡Priestley, John. 174 Lloyd-street, Greenheys, Manchester.
1875. ‡Prince, Thomas. 6 Marlborough-road, Bradford, Yorkshire.
1883. §Prince, Thomas. Horsham-road, Dorking.
1864. *Prior, R. C. A., M.D. 48 York-terrace, Regent's Park, London, N.W.
1846. *Pritchard, Rev. Charles, D.D., F.R.S., F.G.S., F.R.A.S., Professor of Astronomy in the University of Oxford. 8 Keble-terrace, Oxford.
1876. *Pritchard, Urban, M.D., F.R.C.S. 3 George-street, Hanover-square, London, W.
1881. §Procter, John William. Ashcroft, Nunthorpe, York.
1863. ‡Proctor, R. S. Summerhill-terrace, Newcastle-on-Tyne.
Proctor, William. Elmhurst, Higher Erith-road, Torquay.
1885. §Profeit, Dr. Balmoral, N.B.
1863. **Prosser, Thomas. 25 Harrison-place, Newcastle-on-Tyne.*
1863. ‡Proud, Joseph. South Hetton, Newcastle-on-Tyne.
1884. *Proudfoot, Alexander. 2 Phillips-place, Montreal, Canada.
1879. *Prouse, Oswald Milton, F.G.S., F.R.G.S. 4 Cambridge-villas, Richmond Park-road, Kingston-on-Thames.
1865. ‡Prowse, Albert P. Whitchurch Villa, Mannamead, Plymouth.
1872. *Pryor, M. Robert. Weston Manor, Stevenage, Herts.
1871. *Puckle, Thomas John. Woodcote-grove, Carshalton, Surrey.
1873. ‡Pullan, Lawrence. Bridge of Allan, N.B.
1867. *Pullar, Robert, F.R.S.E. Tayside, Perth.
1883. *Pullar, Rufus D., F.C.S. Tayside, Perth.
1842. *Pumphrey, Charles. Southfield, King's Norton, near Birmingham.
Punnet, Rev. John, M.A., F.C.P.S. St. Earth, Cornwall.
1885. §Purdie, Professor Thomas. St. Andrews, N.B.
1852. ‡Purdon, Thomas Henry, M.D. Belfast.
1860. ‡Purdy, Frederick, F.S.S., Principal of the Statistical Department of the Poor Law Board, Whitehall, London. Victoria-road, Kensington, London, W.
1881. ‡Purey-Cust, Very Rev. Arthur Percival, M.A., Dean of York. The Deanery, York.
1882. §Purrott, Charles. West End, near Southampton.
1874. ‡Purser, Frederick, M.A. Rathmines, Dublin.
1866. ‡Purser, Professor John, M.A., M.R.I.A. Queen's College, Belfast.
1878. ‡Purser, John Mallet. 3 Wilton-terrace, Dublin.
1884. *Purves, W. Laidlaw. 20 Stafford-place, Oxford-street, London, W.
1860. *Pusey, S. E. B. Bouverie. Pusey House, Faringdon.
1883. §Pye-Smith, Arnold. 16 Fairfield-road, Croydon.
1883. §Pye-Smith, Mrs. 16 Fairfield-road, Croydon.
1868. §Pye-Smith, P. H., M.D. 54 Harley-street, W.; and Guy's Hospital, London, S.E.
1879. §Pye-Smith, R. J. 6 Surrey-street, Sheffield.
1861. *Pyne, Joseph John. The Willows, Albert-road, Southport.

1870. ‡Rabbits, W. T. Forest Hill, London, S.E.
1870. ‡Radcliffe, D. R. Phœnix Safe Works, Windsor, Liverpool.
1877. ‡Radford, George D. Mannamead, Plymouth.
1879. ‡Radford, R. Heber. Wood Bank, Pitsmoor, Sheffield.
1860. ‡Radcliffe, Charles Bland, M.D. 25 Cavendish-square, London, W.
*Radford, William, M.D. Sidmount, Sidmouth.
1855. *Radstock, Lord. 70 Portland-place, London, W.

Year of Election.

1878. ‡Rae, John, M.D., LL.D., F.R.S., F.R.G.S. 4 Addison-gardens, Kensington, London, W.

1854. ‡Raffles, Thomas Stamford. 13 Abercromby-square, Liverpool.

1864. ‡Rainey, James T. St. George's Lodge, Bath.

Rake, Joseph. Charlotte-street, Bristol.

1863. ‡Ramsay, Alexander, F.G.S. 2 Cowper-road, Acton, Middlesex, W.

1845. ‡Ramsay, Sir Andrew Crombie, LL.D., F.R.S., F.G.S. 15 Cromwell-crescent, South Kensington, London, S.W.

1884. ‡Ramsay, George G., LL.D., Professor of Humanity in the University of Glasgow. 6 The College, Glasgow.

1884. ‡Ramsay, Mrs. G. G. 6 The College, Glasgow.

1861. ‡Ramsay, John, M.P. Kildalton, Argyleshire.

1884. ‡Ramsay, R. A. 1134 Sherbrooke-street, Montreal, Canada.

1867. **Ramsay, W. F., M.D. 39 Hammersmith-road, West Kensington, London, W.*

1876. *Ramsay, William, Ph.D., Professor of Chemistry in University College, Bristol.

1883. §Ramsay, Mrs. 10 Osborne-road, Clifton, Bristol.

1885. §Ramsay, Major. Straloch, N.B.

1873. *Ramsden, William. Bracken Hall, Great Horton, Bradford, Yorkshire.

1835. *Rance, Henry. St. Andrew's-street, Cambridge.

1869. *Rance, H. W. Henniker, LL.D. 10 Castletown-road, West Kensington, London, S.W.

1860. ‡Randall, Thomas. Grandepoint House, Oxford.

1865. ‡Randel, J. 50 Vittoria-street, Birmingham.

1868. *Ransom, Edwin, F.R.G.S. Ashburnham-road, Bedford.

1863. §Ransom, William Henry, M.D., F.R.S. The Pavement, Nottingham.

1861. ‡Ransome, Arthur, M.A., M.D., F.R.S. Devisdale, Bowdon, Manchester.

Ransome, Thomas. 34 Princess-street, Manchester.

1872. *Ranyard, Arthur Cowper, F.R.A.S. 25 Old-square, Lincoln's Inn, London, W.C.

Rashleigh, Jonathan. 3 Cumberland-terrace, Regent's Park, London, N.W.

1864. ‡Rate, Rev. John, M.A. Lapley Vicarage, Penkridge, Staffordshire.

1870. ‡Rathbone, Benson. Exchange-buildings, Liverpool.

1870. ‡Rathbone, Philip H. Greenbank Cottage, Wavertree, Liverpool.

1870. §Rathbone, R. R. Beechwood House, Liverpool.

1874. ‡Ravenstein, E. G., F.R.G.S. 29 Lambert-road, Brixton, London, S.W.

Rawdon, William Frederick, M.D. Bootham, York.

1870. ‡Rawlins, G. W. The Hollies, Rainhall, Liverpool.

1866. *Rawlinson, Rev. Canon George, M.A., Camden Professor of Ancient History in the University of Oxford. The Oaks, Precincts, Canterbury.

1855. *Rawlinson, Major-General Sir Henry C., K.C.B., LL.D., F.R.S., F.R.G.S. 21 Charles-street, Berkeley-square, London, W.

1875. §Rawson, Sir Rawson W., K.C.M.G., C.B., F.R.G.S. 68 Cornwall-gardens, Queen's-gate, London, S.W.

1883. ‡Ray, Miss Catherine. Mount Cottage, Flask-walk, Hampstead, London, N.W.

1868. *Rayleigh, The Right Hon. Lord, M.A., D.C.L., LL.D., Sec.R.S., F.R.A.S., F.R.G.S. Terling Place, Witham, Essex.

1883. *Rayne, Charles A., M.B., B.Sc., M.R.C.S. 3 Queen-street, Lancaster.

1865. ‡Read, William. Albion House, Epworth, Rawtry.

Year of Election.

*Read, W. H. Rudston, M.A., F.L.S. 12 Blake-street, York.
1870. §READE, THOMAS MELLARD, F.G.S. Blundellsands, Liverpool.
1884. §Readman, J. B., F.R.S.E. 9 Moray-place, Edinburgh.
1862. *Readwin, Thomas Allison, M.R.I.A., F.G.S. 5 Crowhurst-road, Brixton, London, S.W.
1852. *REDFERN, Professor PETER, M.D. 4 Lower-crescent, Belfast.
1863. ‡Redmayne, Giles. 20 New Bond-street, London, W.
Redwood, Isaac. Cae Wern, near Neath, South Wales.
1861. ‡REED, Sir EDWARD J., K.C.B., M.P., F.R.S. 74 Gloucester-road, South Kensington, London, W.
1875. ‡Rees-Mogg, W. Wooldridge. Cholwell House, near Bristol.
1881. §Reid, Arthur S., B.A., F.G.S. Trinity College, Glenalmond, N.B.
1883. *REID, CLEMENT, F.G.S. 28 Jermyn-street, London, S.W.
1876. ‡Reid, James. 10 Woodside-terrace, Glasgow.
1884. ‡Reid, Rev. James, B.A. Bay City, Michigan, U.S.A.
1850. ‡Reid, William, M.D. Cruivie, Cupar, Fife.
1881. ‡Reid, William. 19½ Blake-street, York.
1875. §REINOLD, A. W., M.A., F.R.S., Professor of Physical Science in the Royal Naval College, Greenwich, S.E.
1863. §RENALS, E. 'Nottingham Express' Office, Nottingham.
1863. ‡*Rendel, G. Benwell, Newcastle-on-Tyne.*
1885. §Rennett, Dr. 12 Golden-square, Aberdeen.
1867. ‡Renny, W. W. 8 Douglas-terrace, Broughty Ferry, Dundee.
1884. ‡Retallack, Captain Francis. 6 Beauchamp-avenue, Leamington.
1883. **Reynolds, A. H. 12 Leicester-street, Southport.*
1871. ‡REYNOLDS, JAMES EMERSON, M.A., F.R.S., F.C.S., M.R.I.A., Professor of Chemistry in the University of Dublin. The Laboratory, Trinity College, Dublin.
1870. *REYNOLDS, OSBORNE, M.A., LL.D., F.R.S., M.Inst.C.E., Professor of Engineering in Owens College, Manchester. Fallowfield, Manchester.
1858. §REYNOLDS, RICHARD, F.C.S. 13 Briggate, Leeds.
1883. ‡Rhodes, Dr. James. 25 Victoria-street, Glossop.
1858. *Rhodes, John. 18 Albion-street, Leeds.
1877. *Rhodes, John. 360 Blackburn-road, Accrington, Lancashire.
1884. ‡Rhodes, Lieut.-Colonel William. Quebec, Canada.
1877. *Riccardi, Dr. Paul, Secretary of the Society of Naturalists. Via Stimmate, 15, Modena, Italy.
1863. ‡RICHARDSON, BENJAMIN WARD, M.A., M.D., LL.D., F.R.S. 25 Manchester-square, London, W.
1861. ‡Richardson, Charles. 10 Berkeley-square, Bristol.
1869. *Richardson, Charles. 4 Northumberland-avenue, Putney, S.W.
1863. *Richardson, Edward. Warkworth, Northumberland.
1882. §Richardson, Rev. George, M.A. The College, Winchester.
1868. *Richardson, George. 4 Edward-street, Werneth, Oldham.
1884. *Richardson, George Straker. Heathfield House, Swansea.
1884. *Richardson, J. Clarke. Derwen Fawr, Swansea.
1870. ‡Richardson, Ralph, F.R.S.E. 10 Magdala-place, Edinburgh.
1881. ‡Richardson, W. B. Elm Bank, York.
1861. ‡Richardson, William. 4 Edward-street, Werneth, Oldham.
1876. §Richardson, William Haden. City Glass Works, Glasgow.
1863. ‡Richter, Otto, Ph.D. 407 St. Vincent-street, Glasgow.
1868. §RICKETTS, CHARLES, M.D., F.G.S. 22 Argyle-street, Birkenhead.
1877. ‡Ricketts, James, M.D. St. Helen's, Lancashire.
*RIDDELL, Major-General CHARLES J. BUCHANAN, C.B., R.A., F.R.S. Oaklands, Chudleigh, Devon.

Year of Election.

1861. *Riddell, Henry B. Whitefield House, Rothbury, Morpeth.
1883. *Rideal, Samuel. Mayow-road, Forest-hill, Kent, S.E.
1872. ‡Ridge, James. 98 Queen's-road, Brighton.
1862. ‡Ridgway, Henry Ackroyd, B.A. Bank Field, Halifax.
1861. ‡Ridley, John. 19 Belsize-park, Hampstead, London, N.W.
1884. ‡Ridout, Thomas. Ottawa, Canada.
1863. *Rigby, Samuel. Fern Bank, Liverpool-road, Chester.
1881. *Rigg, Arthur. 71 Warrington-crescent, London, W.
1883. *Rigg, Edward, M.A. Royal Mint, London, E.
1883. ‡Rigg, F. F., M.A. 32 Queen's-road, Southport.
1883. *Rigge, Samuel Taylor. Halifax.
1873. ‡Ripley, Sir Edward, Bart. Acacia, Apperley, near Leeds.
*RIPON, The Most Hon. the Marquis of, K.G., G.C.S.I., C.I.E., D.C.L., F.R.S., F.L.S., F.R.G.S. 1 Carlton-gardens, London, S.W.
1867. ‡Ritchie, John. Fleuchar Craig, Dundee.
1855. ‡Ritchie, Robert. 14 Hill-street, Edinburgh.
1867 ‡Ritchie, William. Emslea, Dundee.
1869. *Rivington, John. Babbicombe, near Torquay.
1854. ‡Robberds, Rev. John, B.A. Battledown Tower, Cheltenham.
1869. *ROBBINS, JOHN, F.C.S. 57 Warrington-crescent, Maida Vale, London, W.
1878. ‡Roberts, Charles, F.R.C.S. 2 Bolton-row, London, W.
1859. ‡Roberts, George Christopher. Hull.
1870. *ROBERTS, ISAAC, F.G.S. Kennessee, Maghull, Lancashire.
1881. §Roberts, R. D., M.A., D.Sc., F.G.S. Clare College, Cambridge.
1883. ‡ROBERTS, RALPH A. 23 Clyde-road, Dublin.
1879. ‡Roberts, Samuel. The Towers, Sheffield.
1879. ‡Roberts, Samuel, jun. The Towers, Sheffield.
1883. ‡Roberts, William, M.D. 89 Moseley-street, Manchester.
1868. ‡ROBERTS-AUSTEN, W. CHANDLER, F.R.S., F.C.S., Chemist to the Royal Mint, and Professor of Metallurgy in the Royal School of Mines. Royal Mint, London, E.
1883. §Robertson, Alexander. Montreal, Canada.
1884. *Robertson, Andrew. Elmbank, Dorchester-street, Montreal, Canada.
1859. ‡Robertson, Dr. Andrew. Indego, Aberdeen.
1884. ‡Robertson, E. Stanley, M.A. 43 Waterloo-road, Dublin.
1871. ‡Robertson, George, M.Inst.C.E., F.R.S.E. 47 Albany-street, Edinburgh.
1883. †Robertson, George H. The Nook, Gateacre, near Liverpool.
1883. ‡Robertson, Mrs. George H. The Nook, Gateacre, near Liverpool.
1870. *Robertson, John. 4 Albert-road, Southport.
1876. ‡Robertson, R. A. Newthorn, Ayton-road, Pollokshields, Glasgow.
1866. ‡*Robertson, William Tindal, M.D. Nottingham.*
1861. ‡Robinson, Enoch. Dukinfield, Ashton-under-Lyne.
1852. ‡Robinson, Rev. George. Beech Hill, Armagh.
**Robinson, H. Oliver.* 34 *Bishopsgate-street, London, E.C.*
1873. §Robinson, Hugh. 82 Donegall-street, Belfast.
1861. ‡ROBINSON, JOHN, M.Inst.C.E. Atlas Works, Manchester.
1863. ‡Robinson, J. H. Cumberland-row, Newcastle-on-Tyne.
1878. ‡Robinson, John L. 198 Great Brunswick-street, Dublin.
1876. ‡Robinson, M. E. 6 Park-circus, Glasgow.
1881. §Robinson, Richard Atkinson. 195 Brompton-road, London, S.W.
1875. *Robinson, Robert, M.Inst.C.E., F.G.S. 2 West-terrace, Darlington.
1860. ‡Robinson, Admiral Sir Robert Spencer, K.C.B., F.R.S. 61 Eaton-place, London, S.W.
1884. ‡Robinson, Stillman. Columbus, Ohio, U.S.A.
1863. ‡Robinson, T. W. U. Houghton-le-Spring, Durham.

Year of
Election.

1870. ‡Robinson, William. 40 Smithdown-road, Liverpool.
1882. §Robinson, W. Braham. Rosenheim, Westwood Park, Southampton.
1870. *Robson, E. R. Palace Chambers, 9 Bridge-street Westminster, S.W.
1876. ‡Robson, Hazleton R. 14 Royal-crescent West, Glasgow.
1855. ‡Robson, Neil. 127 St. Vincent-street, Glasgow.
1872. *Robson, William. Marchholm, Gillsland-road, Merchiston, Edinburgh.
1885. §Rodger, Edward. 1 Claremont-gardens, Glasgow.
1885. *Rodriguez, Epifanio. 12 John-street, Adelphi, London, W.C.
1872. ‡Rodwell, George F., F.R.A.S., F.C.S. Marlborough College, Wiltshire.
1866. ‡Roe, Thomas. Grove-villas, Sitchurch.
1860. ‡Rogers, James E. Thorold, M.P., Professor of Economic Science and Statistics in King's College, London. Beaumont-street, Oxford.
1867. ‡Rogers, James S. Rosemill, by Dundee.
1883. §Rogers, Major R. Alma House, Cheltenham.
1882. §Rogers, Rev. Saltren, M.A. Gwennap, Redruth, Cornwall.
1870. ‡Rogers, T. L., M.D. Rainhill, Liverpool.
1883. ‡Rogers, Thomas Stanley, LL.B. 77 Albert-road, Southport.
1884. *Rogers, Walter M. Lamowa, Falmouth.
1876. §Rollit, Sir A. K., B.A., LL.D., D.C.L., F.R.A.S., Hon. Fellow K.C.L. Thwaite House, Cottingham, East Yorkshire.
1866. ‡*Rolph, G. F.*
1876. ‡Romanes, George John, M.A., LL.D., F.R.S., F.L.S. 18 Cornwall-terrace, Regent's Park, London, N.W.
1846. ‡Ronalds, Edmund, Ph.D. Stewartfield, Bonnington, Edinburgh.
1869. ‡Roper, C. H. Magdalen-street, Exeter.
1872. ‡Roper, Freeman Clarke Samuel, F.L.S., F.G.S. Palgrave House, Eastbourne.
1881. *Roper, W. O. Eadenbreck, Lancaster.
1855. *Roscoe, Sir Henry Enfield, B.A., Ph.D., LL.D., M.P., F.R.S., F.C.S., Professor of Chemistry in Owens College, Manchester.
1883. *Rose, J. Holland, M.A. Ventnor College, Ventnor, Isle of Wight.
1885. §Ross, Alexander. Riverfield, Inverness.
1874. ‡Ross, Alexander Milton, M.A., M.D., F.G.S. Toronto, Canada.
1857. ‡Ross, David, LL.D. 32 Nelson-street, Dublin.
1880. §Ross, Captain G. E. A., F.R.G.S. Forfar House, Cromwell-road, London, S.W.
1872. ‡Ross, James, M.D. Tenterfield House, Waterfoot, near Manchester.
1859. *Ross, Rev. James Coulman. Baldon Vicarage, Oxford.
1874. ‡Ross, Rev. William. Chapelhill Manse, Rothesay, Scotland.
1880. ‡Ross, Colonel William Alexander. Acton House, Acton, London, W.
1869. *Rosse, The Right Hon. the Earl of, B.A., D.C.L., LL.D., F.R.S., F.R.A.S., M.R.I.A. Birr Castle, Parsonstown, Ireland.
1865. *Rothera, George Bell. 17 Waverley-street, Nottingham.
1876. ‡Rottenburgh, Paul. 13 Albion-crescent, Glasgow.
1884. *Rouse, M. L. 343 Church-street, Toronto, Canada.
1861. ‡Routh, Edward J., M.A., D.Sc., F.R.S., F.R.A.S., F.G.S. St. Peter's College, Cambridge.
1881. ‡Routh, Rev. William, M.A. Clifton Green, York.
1872. **Row, A. V. Nursing Observatory, Daba-gardens, Vizagapatam, India. (Care of Messrs. King & Co., 45 Pall Mall, London, S.W.)*
1861. ‡Rowan, David. Elliot-street, Glasgow.
1883. ‡Rowan, Frederick John. 134 St. Vincent-street, Glasgow.
1881. ‡Rowe, Rev. G. Lord Mayor's Walk, York.

Year of Election.

1865. §Rowe, Rev. John. Load Vicarage, Langport, Somerset.
1877. §ROWE, J. BROOKING, F.L.S., F.S.A. 16 Lockyer-street, Plymouth.
1855. *ROWNEY, THOMAS H., Ph.D., F.C.S., Professor of Chemistry in Queen's College, Galway. Salerno, Salthill, Galway.
1881. *Rowntree, Joseph. 24 St. Mary's, York.
1881. *ROWNTREE, J. S. The Mount, York.
1862. ‡Rowsell, Rev. Evan Edward, M.A. Hambledon Rectory, Godalming.
1876. ‡Roxburgh, John. 7 Royal Bank-terrace, Glasgow.
1883. ‡Roy, Charles S., M.D., F.R.S., Professor of Pathology in the University of Cambridge. Trinity College, Cambridge.
1885. §Roy, John. 33 Belvidere-street, Aberdeen.
1861. *Royle, Peter, M.D., L.R.C.P., M.R.C.S. 27 Lever-street, Manchester.
1875. ‡RÜCKER, A. W., M.A., F.R.S. Errington, Clapham Park, London, S.W.
1869. §RUDLER, F. W., F.G.S. The Museum, Jermyn-street, London, S.W.
1882. ‡Rumball, Thomas, M.Inst.C.E. 8 Queen Anne's-gate, London, S.W.
1884. §Runtz, John. Linton Lodge, Lordship-road, Stoke Newington, London, N.
1847. ‡RUSKIN, JOHN, M.A., F.G.S. Brantwood, Coniston, Ambleside.
1875. *Russell, The Hon. F. A. R. Pembroke Lodge, Richmond Park, Surrey.
1884. §Russell, George. Hoe Park House, Plymouth.
1883. *Russell, J. W. Merton College, Oxford.
1865. ‡Russell, James, M.D. 91 Newhall-street, Birmingham.
Russell, John. 39 Mountjoy-square, Dublin.
1876. §Russell, R., F.G.S. 1 Sea View, St. Bees, Carnforth.
1862. §RUSSELL, W. H. L., B.A., F.R.S. 3 Ridgmount-terrace, Highgate, London, N.
1852. *RUSSELL, WILLIAM J., Ph.D., F.R.S., F.C.S., Lecturer on Chemistry in St. Bartholomew's Medical College. 34 Upper Hamilton-terrace, St. John's Wood, London, N.W.
1883. *Ruston, Joseph, M.P. Monk's Manor, Lincoln.
1871. §RUTHERFORD, WILLIAM, M.D., F.R.S., F.R.S.E., Professor of the Institutes of Medicine in the University of Edinburgh.
1881. ‡Rutson, Albert. Newby Wiske, Thirsk.
Rutson, William. Newby Wiske, Northallerton, Yorkshire.
1879. ‡Ruxton, Rear-Admiral Fitzherbert, R.N., F.R.G.S. 41 Cromwell-gardens, London, S.W.
1875. ‡Ryalls, Charles Wager, LL.D. 3 Brick-court, Temple, London, E.C.
1865. ‡Ryland, Thomas. The Redlands, Erdington, Birmingham.
1861. *RYLANDS, THOMAS GLAZEBROOK, F.L.S., F.G.S. Highfields, Thelwall, near Warrington.

1883. *Sabine, Robert. 3 Great Winchester-street-buildings, London, E.C.
1883. ‡Sadler, Robert. 7 Lulworth-road, Birkdale, Southport.
1871. ‡Sadler, Samuel Champernowne. Purton Court, Purton, near Swindon, Wiltshire.
1885. §Saint, W. Johnstone. Woodhill, Braemar, N.B.
1866. *St. Albans, His Grace the Duke of. Bestwood Lodge, Arnold, near Nottingham.
1881. ‡Salkeld, William. 4 Paradise-terrace, Darlington.
1857. ‡SALMON, Rev. GEORGE, D.D., D.C.L., LL.D., F.R.S., Regius Professor of Divinity in the University of Dublin. Trinity College, Dublin.

Year of Election.

1883. ‡Salmond, Robert G. The Nook, Kingswood-road, Upper-Norwood, S.E.
1873. *Salomons, Sir David, Bart. Broomhill, Tunbridge Wells.
1883. §Salt, Shirley H., M.A. 73 Queensborough-terrace, London, W.
1872. ‡SALVIN, OSBERT, M.A., F.R.S., F.L.S. Hawksfold, Haslemere.
1861. *Samson, Henry. 6 St. Peter's-square, Manchester.
1861. *Sandeman, Archibald, M.A. Garry Cottage, Perth.
1876. ‡Sandeman, David. Woodlands, Lenzie, Glasgow.
1883. ‡Sandeman, E. 53 Newton-street, Greenock.
1878. ‡Sanders, Alfred, F.L.S. 2 Clarence-place, Gravesend, Kent.
1883. ‡Sanders, Charles J. B. Pennsylvania, Exeter.
1884. ‡Sanders, Henry. 185 James-street, Montreal, Canada.
1872. ‡Sanders, Mrs. 8 Powis-square, Brighton.
1883. ‡Sanderson, Surgeon Alfred. East India United Service Club, St. James's-square, London, S.W.
1872. ‡SANDERSON, J. S. BURDON, M.D., LL.D., F.R.S., Professor of Physiology in the University of Oxford. 50 Banbury-road, Oxford.
1883. §Sanderson, Mrs. Burdon. 50 Banbury-road, Oxford.
Sandes, Thomas, A.B. Sallow Glin, Tarbert, Co. Kerry.
1864. ‡Sandford, William. 9 Springfield-place, Bath.
1873. ‡Sands, T. C. 24 Spring-gardens, Bradford, Yorkshire.
1868. ‡Saunders, A., M.Inst.C.E King's Lynn.
1881. §SAUNDERS, HOWARD, F.L.S., F.Z.S. 7 Radnor-place, London, W.
1883. ‡Saunders, Rev. J. C. Cambridge.
1846. ‡SAUNDERS, TRELAWNEY W. India Office, London, S.W.
1864. ‡Saunders, T. W., Recorder of Bath. 1 Priory-place, Bath.
1884. ‡Saunders, William. London, Ontario, Canada.
1884. ‡Saunderson, C. E. 26 St. Famille-street, Montreal, Canada.
1871. §Savage, W. D. Ellerslie House, Brighton.
1883. ‡Savage, W. W. 109 St. James's-street, Brighton.
1883. §Savery, G. M., M.A. Cotlake House, Taunton.
1872. *Sawyer, George David, F.R.M.S. 55 Buckingham-place, Brighton.
1868. ‡*Sawyer, John Robert. Grove-terrace, Thorpe Hamlet, Norwich.*
1884. ‡Sayre, Robert H. Bethlehem, Pennsylvania, U.S.A.
1883. *Scarborough, George. Holly Bank, Halifax, Yorkshire.
1883. ‡Scarisbrick, Charles. 5 Palace-gate, Kensington, London, W.
1884. §Scarth, William Bain. Winnipeg, Manitoba, Canada.
1868. §Schacht, G. F. 1 Windsor-terrace, Clifton, Bristol.
1879. *SCHÄFER, E. A., F.R.S., M.R.C.S., Professor of Physiology in University College, London. Boreham Wood, Elstree, Herts.
1883. ‡Schäfer, Mrs. Boreham Wood, Elstree, Herts.
1880. *Schemmann, Louis Carl. Hamburg. (Care of Messrs. Allen Everitt & Sons, Birmingham.)
1842. Schofield, Joseph. Stubley Hall, Littleborough, Lancashire.
1883. ‡Schofield, William. Alma-road, Birkdale, Southport.
1885. §Scholes, L. 46 Cecil-street, Bury, Lancashire.
1876. ‡Schuman, Sigismond. 7 Royal Bank-place, Glasgow.
SCHUNCK, EDWARD, F.R.S., F.C.S. Oaklands, Kersall Moor, Manchester.
1873. *SCHUSTER, ARTHUR, Ph.D., F.R.S., F.R.A.S., Professor of Applied Mathematics in Owens College, Manchester.
1861. *Schwabe, Edmund Salis. Ryecroft House, Cheetham Hill, Manchester.
1847. *SCLATER, PHILIP LUTLEY, M.A., Ph.D., F.R.S., F.L.S., F.G.S., F.R.G.S., Sec.Z.S. 3 Hanover-square, London, W.
1883. *Sclater, William Lutley, B.A., F.Z.S. 3 Hanover-square, London, W.

Year of Election.

1882. *Sclater-Booth, The Right Hon. G., M.P., F.R.S. 74 St. George's-square, London, S.W.
1867. ‡Scott, Alexander. Clydesdale Bank, Dundee.
1881. *Scott, Alexander, M.A., B.Sc. Trinity College, Cambridge.
1882. ‡Scott, Colonel A. de C., R.E. Ordnance Survey Office, Southampton.
1878. ‡Scott, Arthur William, M.A., Professor of Mathematics and Natural Science in St. David's College, Lampeter.
1881. §Scott, Miss Charlotte Angus. Lancashire College, Whalley Range, Manchester.
1876. ‡Scott, Mr. Bailie. Glasgow.
1871. ‡Scott, Rev. C. G. 12 Pilrig-street, Edinburgh.
1885. §Scott, George Jamieson. Bayview House, Aberdeen.
1857. *Scott, Robert H., M.A., F.R.S., F.G.S., F.R.M.S., Secretary to the Council of the Meteorological Office. 6 Elm Park-gardens, London, S.W.
1861. §Scott, Rev. Robert Selkirk, D.D. 16 Victoria-crescent, Dowanhill, Glasgow.
1884. *Scott, Sydney C. 39 King-street, Cheapside, London, E.C.
1858. ‡Scott, William. Holbeck, near Leeds.
1869. ‡Scott, William Bower. Chudleigh, Devon.
1885. §Scott-Moncrieff, W. G. The Castle, Banff.
1881. *Scrivener, A. P. Weston Turvill, Tring.
1883. ‡Scrivener, Mrs. Weston Turvill, Tring.
1859. ‡Seaton, John Love. The Park, Hull.
1880. ‡Sedgwick, Adam, M.A. Trinity College, Cambridge.
1880. ‡Seebohm, Henry, F.L.S., F.Z.S. 6 Tenterden-street, Hanover-square, London, W.
1861. *Seeley, Harry Govier, F.R.S., F.L.S., F.G.S., F.R.G.S., F.Z.S., Professor of Geography in King's College, London. The Vine, Sevenoaks.
1855. ‡Seligman, H. L. 27 St. Vincent-place, Glasgow.
1879. §Selim, Adolphus. 21 Mincing-lane, London, E.C.
1885. §Sempie, Dr. United Service Club, Edinburgh.
1873. ‡Semple, R. H., M.D. 8 Torrington-square, London, W.C.
1858. *Senior, George, F.S.S. Old Whittington, Chesterfield.
1870. *Sephton, Rev. J. 90 Huskisson-street, Liverpool.
1883. §Seville, Miss M. A. Blythe House, Southport.
1875. §Seville, Thomas. Blythe House, Southport.
1873. ‡*Sewell, Rev. E., M.A., F.G.S., F.R.G.S. Ilkley College, near Leeds.*
1868. ‡Sewell, Philip E. Catton, Norwich.
1883. ‡Shadwell, John Lancelot. 21 Nottingham-place, London, W.
*Shaen, William. 15 Upper Phillimore-gardens, Kensington, London, W.
1871. *Shand, James. Fullbrooks, Worcester Park, Surrey.
1867. §Shanks, James. Dens Iron Works, Arbroath, N.B.
1881. ‡Shann, George, M.D. Petergate, York.
1869. *Shapter, Dr. Lewis, LL.D. 1 Barnfield-crescent, Exeter.
1878. ‡Sharp, David, M.B. Bleckley, Shirley Warren, Southampton.
Sharp, Rev. John, B.A. Horbury, Wakefield.
*Sharp, William, M.D., F.R.S., F.G.S. Horton House, Rugby.
Sharp, Rev. William, B.A. Mareham Rectory, near Boston, Lincolnshire.
1883. ‡Sharples, Charles H., F.C.S. 7 Fishergate, Preston.
1854. *Shaw, Charles Wright. 3 Windsor-terrace, Douglas, Isle of Man.
1870. ‡Shaw, Duncan. Cordova, Spain.
1865. ‡Shaw, George. Cannon-street, Birmingham.

Year of Election.

1881. *SHAW, H. S. HELE, Professor of Engineering in University College, Liverpool.
1870. ‡Shaw, John. 21 St. James's-road, Liverpool.
1845. ‡Shaw, John, M.D., F.L.S., F.G.S. Hop House, Boston, Lincolnshire.
1883. *Shaw, W. N., M.A. Emmanuel College, Cambridge.
1884. ‡*Sheafer, Peter W.*
1883. ‡Sheard, J. 42 Hoghton-street, Southport.
1883. §Shearer, Miss A. M. Bushy Hill, Cambuslang, Lanark.
1883. ‡*Shield, Robert. Wing House, near Oldham.*
1884. §Sheldon, Professor J. P. Downton College, near Salisbury.
1878. ‡Shelford, W., C.E. 35A Great George-street, Westminster, S.W.
1881. ‡Shenstone, W. A. Clifton College, Bristol.
1863. ‡Shepherd, A. B. 17 Great Cumberland-place, Hyde Park, London, W.
1885. §Shepherd, Rev. Alexander. Ecclesmechen, Uphall, Edinburgh.
1885. §Shepherd, Charles. 1 Wellington-street, Aberdeen.
1883. ‡Shepherd, James. Birkdale, Southport.
1870. §Shepherd, Joseph. 29 Everton-crescent, Liverpool.
Sheppard, Rev. Henry W., B.A. The Parsonage, Emsworth, Hants.
1883. §Sherlock, David. Lower Leeson-street, Dublin.
1883. §Sherlock, Mrs. David. Lower Leeson-street, Dublin.
1883. ‡Sherlock, Rev. Edgar. Bentham Rectory, *viâ* Lancaster.
1883. *Shillitoe, Buxton, F.R.C.S. 2 Frederick-place, Old Jewry, London, E.C.
1866. ‡Shilton, Samuel Richard Parr. Sneinton House, Nottingham.
1867. ‡Shinn, William C. 4 Varden's-road, Clapham Junction, Surrey, S.W.
1885. §Shirras, G. F. 16 Carden-place, Aberdeen.
1883. ‡Shone, Isaac. Pentrefelin House, Wrexham.
1870. *SHOOLBRED, JAMES N., M.Inst.C.E., F.G.S. 3 Westminster-chambers, London, S.W.
1875. ‡Shore, Thomas W., F.C.S., F.G.S. Hartley Institution, Southampton.
1882. ‡Shore, T. W., jun., B.Sc. Uplands, Woolston, Southampton.
1881. ‡Shuter. James L. 9 Steele's-road, Haverstock Hill, London, N.W.
1883. §Sibly, Miss Martha Agnes. Flook House, Taunton.
1883. *Sidebotham, Edward John. Erlesdene, Bowdon, Cheshire.
1883. *Sidebotham, James Nasmyth. Erlesdene, Bowdon, Cheshire.
1877. *Sidebotham, Joseph Watson. Erlesdene, Bowdon, Cheshire.
1885. *SIDGWICK, HENRY, M.A., Litt.D., Professor of Moral Philosophy in the University of Cambridge. Hillside, Chesterton-road, Cambridge.
1873. ‡Sidgwick, R. H. The Raikes, Skipton.
Sidney, M. J. F. Cowpen, Newcastle-upon-Tyne.
1873. *Siemens, Alexander. 12 Queen Anne's-gate, Westminster, S.W.
1878. ‡Sigerson, Professor George, M.D., F.L.S., M.R.I.A. 3 Clare-street, Dublin.
1859. ‡Sim, John. Hardgate, Aberdeen.
1871. ‡Sime, James. Craigmount House, Grange, Edinburgh.
1862. ‡Simms, James. 138 Fleet-street, London, E.C.
1874. ‡Simms, William. The Linen Hall, Belfast.
1876. ‡Simon, Frederick. 24 Sutherland-gardens, London, W.
1847. ‡Simon, John, C.B., D.C.L., F.R.S., F.R.C.S., Consulting Surgeon to St. Thomas's Hospital. 40 Kensington-square, London, W.
1866. ‡Simons, George. The Park, Nottingham.
1871. *SIMPSON, ALEXANDER R., M.D., Professor of Midwifery in the University of Edinburgh. 52 Queen-street, Edinburgh.

Year of Election.

1883. §Simpson, Byron R. 7 York-road, Birkdale, Southport.
1867. ‡Simpson, G. B. Seafield, Broughty Ferry, by Dundee.
1859. ‡Simpson, John. Maykirk, Kincardineshire.
1863. ‡Simpson, J. B., F.G.S. Hedgefield House, Blaydon-on-Tyne.
1857. ‡SIMPSON, MAXWELL, M.D., LL.D., F.R.S., F.C.S., Professor of Chemistry in Queen's College, Cork.
1883. ‡Simpson, Walter M. 7 York-road, Birkdale, Southport.
Simpson, William. Bradmore House, Hammersmith, London, W.
1884. *Simpson, W. J. R., M.D. Town House, Aberdeen.
1874. ‡Sinclair, Thomas. Dunedin, Belfast.
1884. ‡*Sinclair, Vetch, M.D. 48 Albany-street, Edinburgh.*
1870. *Sinclair, W. P. 19 Devonshire-road, Prince's Park, Liverpool.
1864. *Sircar, Mahendra Lal, M.D. 51 Sankaritola, Calcutta. (Care of Messrs. S. Harraden & Co., 3 Hill's-place, Oxford-street, London, W.)
1865. ‡Sissons, William. 92 Park-street, Hull.
1879. ‡Skertchly, Sydney B. J., F.G.S. 3 Loughborough-terrace, Carshalton, Surrey.
1883. ‡Skillicorne, W. N. 9 Queen's-parade, Cheltenham.
1885. §Skinner, Provost. Inverurie, N.B.
1870. §SLADEN, WALTER PERCY, F.G.S., F.L.S. Orsett House, Ewell, Surrey.
1873. ‡Slater, Clayton. Barnoldswick, near Leeds.
1842. *Slater, William. Park-lane, Higher Broughton, Manchester.
1884. ‡Slattery, James W. 9 Stephen's-green, Dublin.
1877. ‡Sleeman, Rev. Philip, L.Th., F.R.A.S., F.R.M.S. Clifton, Bristol.
1884. ‡Slooten, William Venn. Nova Scotia, Canada.
1849. ‡Sloper, George Elgar. Devizes.
1849. ‡Sloper, Samuel W. Devizes.
1860. ‡Sloper, S. Elgar. Winterton, near Hythe, Southampton.
1867. ‡Small, David. Gray House, Dundee.
1881. ‡Smallshan, John. 81 Manchester-road, Southport.
1885. §Smart, James. Valley Works, Brechin, N.B.
1858. ‡Smeeton, G. H. Commercial-street, Leeds.
1876. §Smellie, Thomas D. 213 St. Vincent-street, Glasgow.
1877. ‡Smelt, Rev. Maurice Allen, M.A., F.R.A.S. Heath Lodge, Cheltenham.
1876. ‡Smieton, James. Panmure Villa, Broughty Ferry, Dundee.
1876. ‡Smieton, John G. 3 Polworth-road, Coventry Park, Streatham, London, S.W.
1867. ‡Smieton, Thomas A. Panmure Villa, Broughty Ferry, Dundee.
1857. ‡Smith, Aquilla, M.D., M.R.I.A. 121 Lower Baggot-street, Dublin.
1872. *Smith, Basil Woodd, F.R.A.S. Branch Hill Lodge, Hampstead Heath, London, N.W.
1874. *Smith, Benjamin Leigh, F.R.G.S. 64 Gower-street, London, W.C.
1873. ‡Smith, C. Sidney College, Cambridge.
1865. ‡SMITH, DAVID, F.R.A.S. 40 Bennett's-hill, Birmingham.
1865. ‡Smith, Frederick. The Priory, Dudley.
1866. *Smith, F. C. Bank, Nottingham.
1855. ‡Smith, George. Port Dundas, Glasgow.
1885. §Smith, Rev. G. A., M.A. 91 Fountainhall-road, Aberdeen.
1860. *Smith, Heywood, M.A., M.D. 18 Harley-street, Cavendish-square, London, W.
1870. ‡Smith, H. L. Crabwall Hall, Cheshire.
1885. §Smith, Rev. James, B.D. Manse of Newhills, N.B.
1871. *Smith, John Alexander, M.D., F.R.S.E., F.S.A.Scot. 10 Palmerston-place, Edinburgh.

Year of
Election.
1876. *Smith, J. Guthrie. 54 West Nile-street, Glasgow.
1874. ‡Smith, John Haigh. 77 Southbank-road, Southport.
Smith, John Peter George. Netherall, Largs, Ayrshire.
1871. ‡Smith, J. William Robertson, M.A., Lord Almoner's Professor of Arabic in the University of Cambridge.
1883. ‡Smith, M. Holroyd. Fern Hill, Halifax.
*Smith, Philip, B.A. The Bays, Parkfields, Putney, S.W.
1860. *Smith, Protheroe, M.D. 42 Park-street, Grosvenor-square, London, W.
1837. Smith, Richard Bryan. Villa Nova, Shrewsbury.
1885. §Smith, Robert H., M.Inst.C.E., Professor of Engineering in the Mason Science College, Birmingham.
1840. *Smith, Robert Mackay. 4 Bellevue-crescent, Edinburgh.
1870. ‡Smith, Samuel. Bank of Liverpool, Liverpool.
1866. ‡Smith, Samuel. 33 Compton-street, Goswell-road, London, E.C.
1873. ‡Smith, Swire. Lowfield, Keighley, Yorkshire.
1867. ‡Smith, Thomas. Dundee.
1867. ‡Smith, Thomas. Poole Park Works, Dundee.
1859. ‡Smith, Thomas James, F.G.S., F.C.S. Hornsea Burton, East Yorkshire.
1884. ‡Smith, Vernon. 127 Metcalfe-street, Ottawa, Canada.
1885. *Smith, Watson. Owens College, Manchester.
1852. ‡Smith, William. Eglinton Engine Works, Glasgow.
1875. *Smith, William. Sundon House, Clifton, Bristol.
1876. ‡Smith, William. 12 Woodside-place, Glasgow.
1883. ‡Smithells, Arthur, B.Sc., Professor of Chemistry in the Yorkshire College, Leeds.
1883. ‡Smithson, Edward Walter. 13 Lendal, York.
1883. ‡Smithson, Mrs. 13 Lendal, York.
1878. ‡Smithson, Joseph S. Balnagowan, Rathmines, Co. Dublin.
1882. §Smithson, T. Spencer. Facit, Rochdale.
1874. ‡Smoothy, Frederick. Bocking, Essex.
1850. *Smyth, Charles Piazzi, F.R.S.E., F.R.A.S., Astronomer Royal for Scotland, Professor of Astronomy in the University of Edinburgh. 15 Royal-terrace, Edinburgh.
1883. ‡Smyth, Rev. Christopher. Woodford Rectory, Thrapston.
1874. ‡Smyth, Henry. Downpatrick, Ireland.
1878. §Smyth, Mrs. Isabella. Wigmore Lodge, Cullenswood-avenue, Dublin.
1857. *Smyth, John, jun., M.A., F.R.M.S. Milltown, Banbridge, Ireland.
1864. ‡Smyth, Warington W., M.A., F.R.S., F.G.S., F.R.G.S., Lecturer on Mining and Mineralogy at the Royal School of Mines, and Inspector of the Mineral Property of the Crown. 5 Inverness-terrace, Bayswater, London, W.
1854. ‡Smythe, General W. J., R.A., F.R.S. Athenæum Club, Pall Mall, London, S.W.
1883. ‡Snape, Joseph. 13 Scarisbrick-street, Southport.
1878. §Snell, H. Saxon. 22 Southampton-buildings, London, W.C.
1879. *Sollas, W. J., M.A., D.Sc., F.R.S.E., F.G.S., Professor of Geology in the University of Dublin. Trinity College, Dublin.
Sorbey, Alfred. The Rookery, Ashford, Bakewell.
1859. *Sorby, H. Clifton, LL.D., F.R.S., F.G.S. Broomfield, Sheffield.
1879. *Sorby, Thomas W. Storthfield, Sheffield.
1865. *Southall, John Tertius. Parkfields, Ross, Herefordshire.
1859. ‡Southall, Norman. 44 Cannon-street West, London, E.C.
1856. ‡Southwood, Rev. T. A. Cheltenham College.
1863. ‡Sowerby, John. Shipcote House, Gateshead, Durham.

Year of Election.

1883. §Spanton, William Dunnett, F.R.C.S. Chatterley House, Hanley, Staffordshire.
1863. *Spark, H. King. Starforth House, Barnard Castle.
1879. ‡*Spence, David. Brookfield House, Freyinghall, Yorkshire.*
1869. *Spence, J. Berger. 31 Lombard-street, London, E.C.
1881. ‡Spencer, Herbert E. Lord Mayor's Walk, York.
1884. ‡Spencer, John, M.Inst.M.E. Globe Tube Works, Wednesbury.
1861. ‡Spencer, John Frederick. 28 Great George-street, London, S.W.
1861. *Spencer, Joseph. Springbank, Old Trafford, Manchester.
1863. *Spencer, Thomas. The Grove, Ryton, Blaydon-on-Tyne, Co. Durham.
1875. ‡Spencer, W. H. Richmond Hill, Clifton, Bristol.
1884. *Spice, Robert Paulson, M.Inst.C.E. 21 Parliament-street, Westminster, S.W.
1864. *Spicer, Henry, B.A., M.P., F.L.S., F.G.S. 14 Aberdeen Park, Highbury, London, N.
1864. *SPILLER, JOHN, F.C.S. 2 St. Mary's-road, Canonbury, London, N.
1878. §Spottiswoode, George Andrew. 3 Cadogan-square, London, S.W.
1864. *Spottiswoode, W. Hugh. 41 Grosvenor-place, London, S.W.
1854. *SPRAGUE, THOMAS BOND, M.A., F.R.S.E. 29 Buckingham-terrace, Edinburgh.
1883. §Spratling, W. J., B.Sc., F.G.S. Maythorpe, 72 Wickham-road, Brockley, S.E.
1853. ‡Spratt, Joseph James. West Parade, Hull.
1884. *Spruce, Samuel. Beech House, Tamworth.
Square, Joseph Elliot, F.G.S. 24 Portland-place, Plymouth.
1877. ‡SQUARE, WILLIAM, F.R.C.S., F.R.G.S. 4 Portland-square, Plymouth.
*Squire, Lovell. 9 Osman-road, Hammersmith, London, W.
1879. ‡Stacye, Rev. John. Shrewsbury Hospital, Sheffield.
1858. *STAINTON, HENRY T., F.R.S., F.L.S., F.G.S. Mountsfield, Lewisham, S.E.
1884. ‡Stancoffe, Frederick. Dorchester-street, Montreal, Canada.
1883. *Stanford, Edward, jun., F.R.G.S. 17 Spring-gardens, London, S.W.
1865. ‡STANFORD, EDWARD C. C. Glenwood, Dalmuir, N.B.
1837. Staniforth, Rev. Thomas. Storrs, Windermere.
1881. *Stanley, William Ford, F.G.S. Cumberlow, South Norwood, Surrey, S.E.
1883. §Stanley, Mrs. Cumberlow, South Norwood, Surrey, S.E.
Stapleton, M. H., M.B., M.R.I.A. 1 Mountjoy-place, Dublin.
1883. ‡Stapley, Alfred M. Marion-terrace, Crewe.
1866. ‡Starey, Thomas R. Daybrook House, Nottingham.
1876. §Starling, John Henry, F.C.S. The Avenue, Erith, Kent.
Staveley, T. K. Ripon, Yorkshire.
1873. *Stead, Charles. Saltaire, Bradford, Yorkshire.
1881. §Stead, W. H. Hexham House, Southport, Lancashire.
1881. ‡Stead, Mrs. W. H. Hexham House, Southport, Lancashire.
1884. ‡Stearns, Sergeant P. U.S. Consul-General, Montreal, Canada.
1873. ‡Steinthal, G. A. 15 Hallfield-road, Bradford, Yorkshire.
1861. ‡Steinthal, H. M. Hollywood, Fallowfield, near Manchester.
1884. ‡Stephen, George. 140 Drummond-street, Montreal, Canada.
1884. ‡Stephen, Mrs. George. 140 Drummond-street, Montreal, Canada.
1884. *Stephens, W. Hudson. Lowville (P.O.), State of New York, U.S.A.
1879. *STEPHENSON, HENRY, J.P. Endcliffe Vale, Sheffield.
1881. ‡Stephenson, J. F. 3 Mount-parade, York.

Year of Election.

1861. *Stern, S. J. Littlegrove, East Barnet, Herts.
1876. ‡Steuart, Walter. City Bank, Pollockshaws, near Glasgow.
1870. *Stevens, Miss Anna Maria. Oak Villa, George-street, Ryde, Isle of Wight.
1880. *Stevens, J. Edward. 6 Carlton-terrace, Swansea.
1868. ‡Stevenson, Henry, F.L.S. Newmarket-road, Norwich.
1878. ‡Stevenson, Rev. James, M.A. 21 Garville-avenue, Rathgar, Dublin.
1863. *STEVENSON, JAMES C., M.P., F.C.S. Westoe, South Shields.
1882. ‡Steward, Rev. C. E., M.A. The Polygon, Southampton.
1885. §Stewart, Rev. Alexander. Heathcot, Aberdeen.
1855. ‡STEWART, BALFOUR, M.A., LL.D., F.R.S., Professor of Natural Philosophy in Owens College, Manchester.
1864. ‡STEWART, CHARLES, M.A., F.L.S. St. Thomas's Hospital, London, S.E.
1885. §Stewart, David. 293 Union-street, Aberdeen.
1875. *Stewart, James, B.A., M.R.C.P.Ed. Dunmurry, Sneyd Park, Clifton, Gloucestershire.
1876. ‡Stewart, William. Violet Grove House, St. George's-road, Glasgow.
1867. ‡Stirling, Dr. D. Perth.
1876. ‡Stirling, William, M.D., D.Sc., F.R.S.E., Professor of Physiology in the University of Aberdeen.
1867. *Stirrup, Mark, F.G.S. Richmond Hill, Bowdon, Cheshire.
1865. *Stock, Joseph S. St. Mildred's, Walmer.
1883. *STOCKER, W. R. Cooper's Hill, Staines.
1864. ‡STODDART, WILLIAM WALTER, F.G.S., F.C.S. Grafton Lodge, Sneyd Park, Bristol.
1854. ‡Stoess, Le Chevalier Ch. de W. (Bavarian Consul). Liverpool.
1845. *STOKES, GEORGE GABRIEL, M.A., D.C.L., LL.D., Pres. R.S., Lucasian Professor of Mathematics in the University of Cambridge. Lensfield Cottage, Cambridge.
1862. ‡STONE, EDWARD JAMES, M.A., F.R.S., F.R.A.S., Director of the Radcliffe Observatory, Oxford.
1874. ‡Stone, J. Harris, B.A., F.L.S., F.C.S. 11 Sheffield-gardens, Kensington, London, W.
1876. ‡Stone, Octavius C., F.R.G.S. Springfield, Nuneaton.
1883. §Stone, Thomas William. 189 Goldhawk-road, Shepherd's Bush, London, W.
1859. ‡STONE, Dr. WILLIAM H. 14 Dean's-yard, Westminster, S.W.
1857. ‡STONEY, BINDON B., LL.D., F.R.S., M.Inst.C.E., M.R.I.A., Engineer of the Port of Dublin. 14 Elgin-road, Dublin.
1878. *Stoney, G. Gerald. 9 Palmerston Park, Dublin.
1861. *STONEY, GEORGE JOHNSTONE, M.A., F.R.S., M.R.I.A. 9 Palmerston Park, Dublin.
1876. §Stopes, Henry, F.G.S. Kenwyn, Cintra Park, Upper Norwood, S.E.
1883. §Stopes, Mrs. Kenwyn, Cintra Park, Upper Norwood, S.E.
1883. ‡Stopes, Miss Lucy. 84 East Hill, Colchester.
1854. ‡Store, George. Prospect House, Fairfield, Liverpool.
1873. ‡Storr, William. The 'Times' Office, Printing-house-square, London, E.C.
1884. §Storrs, George H. Fern Bank, Stalybridge.
1859. §Story, Captain James Hamilton. 17 Bryanston-square, London, W.
1874. ‡Stott, William. Scar Bottom, Greetland, near Halifax, Yorkshire.
1871. *STRACHEY, Lieut.-General RICHARD, R.E., C.S.I., F.R.S., F.R.G.S., F.L.S., F.G.S. 69 Lancaster-gate, Hyde Park, London, W.

Year of
Election.

1881. ‡Strahan, Aubrey, M.A., F.G.S. Geological Museum, Jermyn-street, London, S.W.
1876. ‡Strain, John. 143 West Regent-street, Glasgow.
1863. ‡Straker, John. Wellington House, Durham.
1882. ‡Strange, Rev. Cresswell, M.A. Edgbaston Vicarage, Birmingham.
1881. ‡Strangways, C. Fox, F.G.S. Geological Museum, Jermyn-street, London, S.W.
*Strickland, Charles. 21 Fitzwilliam-place, Dublin.
1879. ‡Strickland, Sir Charles W., K.C.B. Hildenley-road, Malton.
Strickland, William. French Park, Roscommon, Ireland.
1884. ‡Stringham, Irving. The University, Berkeley, California, U.S.A.
1859. ‡Stronach, William, R.E. Ardmellie, Banff.
1883. §Strong, Henry J., M.D. Whitgift House, Croydon.
1867. ‡Stronner, D. 14 Princess-street, Dundee.
1876. *Struthers, John, M.D., LL.D., Professor of Anatomy in the University of Aberdeen.
1878. ‡Strype, W. G. Wicklow.
1876. *Stuart, Charles Maddock. High School, Newcastle, Staffordshire.
1872. *Stuart, Rev. Edward A., M.A. 116 Grosvenor-road, Highbury New Park, London, N.
1884. ‡Stuart, Dr. W. Theophilus. 183 Spadina-avenue, Toronto, Canada.
1885. §Stump, Edward C. Belgrave-road, Oldham.
1879. *Styring, Robert. 3 Hartshead, Sheffield.
1857. ‡Sullivan, William K., Ph.D., M.R.I.A. Queen's College, Cork.
1883. §Summers, Alfred. Sunnyside, Ashton-under-Lyne.
1883. ‡Summers, William, M.P. Sunnyside, Ashton-under-Lyne.
1884. ‡Sumner, George. 107 Stanley-street, Montreal, Canada.
1883. ‡Sutcliffe, J. S., J.P. Beech House, Bacup.
1873. ‡Sutcliffe, J. W. Sprink Bank, Bradford, Yorkshire.
1873. ‡Sutcliffe, Robert. Idle, near Leeds.
1863. ‡Sutherland, Benjamin John. 10 Oxford-street, Newcastle-on-Tyne.
1862. *Sutherland, George Granville William, Duke of, K.G., F.R.S., F.R.G.S. Stafford House, London, S.W.
1884. ‡Sutherland, J. C. Richmond, Quebec, Canada.
1863. ‡Sutton, Francis, F.C.S. Bank Plain, Norwich.
1881. ‡Sutton, William. Town Hall, Southport.
1881. ‡Swales, William. Ashville, Holgate-road, York.
1876. ‡Swan, David, jun. Braeside, Maryhill, Glasgow.
1881. §Swan, Joseph W. Mosley-street, Newcastle-on-Tyne.
1861. *Swan, Patrick Don S. Kirkcaldy, N.B.
1862. *Swan, William, LL.D., F.R.S.E., Professor of Natural Philosophy in the University of St. Andrews, N.B.
1862. *Swann, Rev. S. Kirke, F.R.A.S. Forest Hill Lodge, Warsop, Mansfield, Nottinghamshire.
1879. ‡Swanwick, Frederick. Whittington, Chesterfield.
1883. ‡Sweeting, Rev. T. E. 50 Roe-lane, Southport.
Sweetman, Walter, M.A., M.R.I.A. 4 Mountjoy-square North, Dublin.
1870. *Swinburne, Sir John, Bart., M.P. Capheaton, Newcastle-on-Tyne.
1863. ‡Swindell, J. S. E. Summerhill, Kingswinford, Dudley.
1885. §Swindells, Miss. Springfield House, Ilkley, Yorkshire.
1873. *Swinglehurst, Henry. Hincaster House, near Milnthorpe.
1858. ‡Sydney, The Right Rev. Alfred Barry, Bishop of, D.D., D.C.L. Sydney.
1883. §Sykes, Alfred. Highfield, Huddersfield.
1873. §Sykes, Benjamin Clifford, M.D. Cleckheaton.
1847. ‡*Sykes, H. P. 47 Albion-street, Hyde Park, London, W.*

Year of Election.

1862. ‡Sykes, Thomas. Cleckheaton.
1847. ‡*Sykes, Captain W. H. F. 47 Albion-street, Hyde Park, London, W.*
SYLVESTER, JAMES JOSEPH, M.A., D.C.L., LL.D., F.R.S., Savilian Professor of Geometry in the University of Oxford. Oxford.
1870. ‡SYMES, RICHARD GLASCOTT, B.A., F.G.S. Geological Survey of Ireland, 14 Hume-street, Dublin.
1885. §Symington, Johnson, M.D. 10 Warrender Park-crescent, Edinburgh.
1881. *Symington, Thomas. 13 Dundas-street, Edinburgh.
1856. *Symonds, Frederick, M.A., F.R.C.S. 35 Beaumont-street, Oxford.
1859. ‡Symonds, Captain Thomas Edward, R.N. 10 Adam-street, Adelphi, London, W.C.
1860. ‡SYMONDS, Rev. W. S., M.A., F.G.S. Pendock Rectory, Worcestershire.
1859. §SYMONS, G. J., F.R.S., Sec.R.M.S. 62 Camden-square, London, N.W.
1883. ‡Symons, Simon. Belfast House, Farquhar-road, Norwood, S.E.
1855. *SYMONS, WILLIAM, F.C.S. 26 Joy-street, Barnstaple.
Synge, Francis. Glanmore, Ashford, Co. Wicklow.
1872. ‡Synge, Major-General Millington, R.E., F.S.A., F.R.G.S. United Service Club, Pall Mall, London, S.W.

1865. ‡Tailyour, Colonel Renny, R.E. Newmanswalls, Montrose, N.B.
1877. *TAIT, LAWSON, F.R.C.S. The Crescent, Birmingham.
1871. ‡TAIT, PETER GUTHRIE, F.R.S.E., Professor of Natural Philosophy in the University of Edinburgh. George-square, Edinburgh.
1867. ‡TAIT, P. M., F.R.G.S., F.S.S. Oriental Club, Hanover-square, London, W.
1883. §Tapscott, R. L. 41 Parkfield-road, Prince's Park, Liverpool.
1866. ‡Tarbotton, Marrott Ogle, M.Inst.C.E., F.G.S. Newstead-grove, Nottingham.
1878. ‡TARPEY, HUGH. Dublin.
1861. *Tarratt, Henry W. Ferniebrae, Dean Park, Bournemouth.
1856. ‡Tartt, William Macdonald, F.S.S. Sandford-place, Cheltenham.
1857. *Tate, Alexander. Longwood, Whitehouse, Belfast.
1870. ‡Tate, Norman A. 7 Nivell-chambers, Fazackerley-street, Liverpool.
1858. *Tatham, George, J.P. Springfield Mount, Leeds.
1876. ‡Tatlock, Robert R. 26 Burnbank-gardens, Glasgow.
1879. ‡Tattershall, William Edward. 15 North Church-street, Sheffield.
1878. *Taylor, A. Claude. Clinton-terrace, Derby-road, Nottingham.
1884. *Taylor, Rev. Charles, D.D. St. John's Lodge, Cambridge.
Taylor, Frederick. Laurel Cottage, Rainhill, near Prescot, Lancashire.
1874. ‡Taylor, G. P. Students' Chambers, Belfast.
1881. *Taylor, H. A. 25 Collingham-road, South Kensington, London, S.W.
1884. *Taylor, H. M., M.A. Trinity College, Cambridge.
1882. *Taylor, Herbert Owen, M.D. 17 Castlegate, Nottingham.
1879. ‡Taylor, John. Broomhall-place, Sheffield.
1861. *Taylor, John, M.Inst.C.E., F.G.S. 6 Queen-street-place, Upper Thames-street, London, E.C.
1873. ‡TAYLOR, JOHN ELLOR, Ph.D., F.L.S., F.G.S. The Mount, Ipswich.
1881. *Taylor, John Francis. Holly Bank House, York.
1865. ‡Taylor, Joseph. 99 Constitution-hill, Birmingham.
1883. ‡Taylor, Michael W., M.D. Hatton Hall, Penrith.
1876. ‡Taylor, Robert. 70 Bath-street, Glasgow.
1878. ‡Taylor, Robert, J.P., LL.D. Corballis, Drogheda.
1884. *Taylor, Miss S. Oak House, Shaw, near Oldham.

Year of Election.

1881. ‡Taylor, Rev. S. B., M.A., Chaplain of Lower Assam, Gauhatti, Assam. (Care of Messrs. Grindlay & Co., 55 Parliament-street, London, S.W.)
1883. ‡Taylor, S. Leigh. Birklands, Westcliffe-road, Birkdale, Southport.
1870. ‡Taylor, Thomas. Aston Rowant, Tetsworth, Oxon.
1883. ‡*Taylor, William. Park-road, Southport.*
1883. ‡Taylor, William, M.D. 21 Crockherbtown, Cardiff.
1884. ‡Taylor-Whitehead, Samuel, J.P. Burton Closes, Bakewell.
1858. ‡Teale, Thomas Pridgin, jun. 20 Park-row, Leeds.
1885. §Teall, J. J. H., M.A., F.G.S. 12 Cumberland-road, Kew, Surrey.
1880. ‡Tebb, Miss. 7 Albert-road, Regent's Park, London, N.W.
1869. ‡Teesdale, C. S. M. Whyke House, Chichester.
1876. *Temperley, Ernest, M.A. Queen's College, Cambridge.
1879. ‡Temple, Lieutenant George T., R.N., F.R.G.S. The Nash, near Worcester.
1880. §Temple, Sir Richard, Bart., G.C.S.I., C.I.E., D.C.L., LL.D., M.P., F.R.G.S. Athenæum Club, London, S.W.
1863. ‡Tennant, Henry. Saltwell, Newcastle-on-Tyne.
1882. §Terrill, William. 3 Hanover-street, Swansea.
1881. ‡Terry, Mr. Alderman. Mount-villas, York.
1883. ‡Tetley, C. F. The Brewery, Leeds.
1883. ‡Tetley, Mrs. C. F. The Brewery, Leeds.
1866. ‡Thackeray, J. L. Arno Vale, Nottingham.
1882. *Thane, George Dancer, Professor of Anatomy in University College, Gower-street, London, W.C.
1885. §Thin, Dr. George, 22 Queen Anne-street, London, W.
1871. ‡Thin, James. 7 Rillbank-terrace, Edinburgh.
1871. ‡Thiselton-Dyer, W. T., C.M.G., M.A., B.Sc., F.R.S., F.L.S. 11 Brunswick-villas, Kew Gardens-road, Kew.
1835. Thom, John. Lark-hill, Chorley, Lancashire.
1870. ‡Thom, Robert Wilson. Lark-hill, Chorley, Lancashire.
1871. ‡Thomas, Ascanius William Nevill. Chudleigh, Devon.
1875. *Thomas, Christopher James. Drayton Lodge, Redland, Bristol.
1883. ‡Thomas, Ernest C., B.A. 13 South-square, Gray's Inn, London, W.C.
1884. ‡Thomas, F. Wolferstan. Molson's Bank, Montreal, Canada.
Thomas, George. Brislington, Bristol.
1875. ‡Thomas, Herbert. Ivor House, Redlands, Bristol.
1869. ‡Thomas, H. D. Fore-street, Exeter.
1881. ‡Thomas, J. Blount. Southampton.
1869. ‡Thomas, J. Henwood, F.R.G.S. Custom House, London, E.C.
1880. *Thomas, Joseph William, F.C.S. The Laboratory, West Wharf, Cardiff.
1883. ‡Thomas, P. Bossley. 4 Bold-street, Southport.
1883. §Thomas, T. H. 45 The Walk, Cardiff.
1883. ‡Thomas, William. Lan, Swansea.
1875. ‡Thompson, Arthur. 12 St. Nicholas-street, Hereford.
1883. ‡Thompson, Miss C. E. Heald Bank, Bowdon, Manchester.
1885. §Thompson, D'Arcy W., B.A., Professor of Physiology in University College, Dundee. University College, Dundee.
1882. ‡Thompson, Charles O. Terre Haute, Indiana, U.S.A.
1883. *Thompson, Francis. 1 Avenue-villas, St. Peter's-road, Croydon.
1859. ‡Thompson, George, jun. Pitmedden, Aberdeen.
Thompson, Harry Stephen. Kirby Hall, Great Ouseburn, Yorkshire.
1870. ‡Thompson, Sir Henry. 35 Wimpole-street, London, W.
1883. *Thompson, Henry G., M.D. 8 Addiscombe-villas, Croydon.
Thompson, Henry Stafford. Fairfield, near York.

Year of Election.

1883. *Thompson, Isaac Cooke, F.R.M.S. Woodstock, Waverley-road, Liverpool.

1861. *Thompson, Joseph. Riversdale, Wilmslow, Manchester.

1864. ‡THOMPSON, Rev. JOSEPH HESSELGRAVE, B.A. Cradley, near Brierley Hill.

1873. ‡Thompson, M. W. Guiseley, Yorkshire.

1876. *Thompson, Richard. Park-street, The Mount, York.

1883. ‡Thompson, Richard. Bramley Mead, Whalley, Lancashire.

1874. ‡Thompson, Robert. Walton, Fortwilliam Park, Belfast.

1876. ‡THOMPSON, SILVANUS PHILLIPS, B.A., D.Sc., F.R.A.S., Professor of Physics in the City and Guilds of London Institute, Finsbury Technical Institute, E.C.

1884. ‡Thompson, Sydney de Courcy. 16 Canonbury-park South, London, N.

1883. *Thompson, T. H. Heald Bank, Bowdon, Manchester.

1863. ‡Thompson, William. 11 North-terrace, Newcastle-on-Tyne.

1867. ‡Thoms, William. Magdalen-yard-road, Dundee.

Thomson, Guy. Oxford.

1850. *THOMSON, Professor JAMES, M.A., LL.D., D.Sc., F.R.S. L. & E. 2 Florentine-gardens, Hillhead-street, Glasgow.

1868. §THOMSON, JAMES, F.G.S. 3 Abbotsford-place, Glasgow.

*Thomson, James Gibson. 14 York-place, Edinburgh.

1876. ‡Thomson, James R. Mount Blow, Dalmuir, Glasgow.

1883. ‡THOMSON, J. J., M.A., F.R.S., Professor of Experimental Physics in the University of Cambridge. Trinity College, Cambridge.

1871. *THOMSON, JOHN MILLAR, F.C.S. King's College, London, W.C.

1871. ‡Thomson, Robert, LL.B. 12 Rutland-square, Edinburgh.

1847. *THOMSON, Sir WILLIAM, M.A., LL.D., D.C.L., F.R.S. L. & E., F.R.A.S., Professor of Natural Philosophy in the University of Glasgow. The University, Glasgow.

1877. *Thomson, Lady. The University, Glasgow.

1874. §THOMSON, WILLIAM, F.R.S.E., F.C.S. Royal Institution, Manchester.

1880. §Thomson, William J. Ghyllbank, St. Helen's.

1871. ‡Thornburn, Rev. David, M.A. 1 John's-place, Leith.

1852. ‡Thornburn, Rev. William Reid, M.A. Starkies, Bury, Lancashire.

1867. ‡Thornton, Thomas. Dundee.

1883. §Thorowgood, Samuel. Castle-square, Brighton.

1845. ‡Thorp, Dr. Disney. Lyppiatt Lodge, Suffolk Lawn, Cheltenham.

1881. ‡Thorp, Fielden. Blossom-street, York.

1871. ‡Thorp, Henry. Briarleigh, Sale, near Manchester.

1881. *Thorp, Josiah. 17 Marmaduke-street, Liverpool.

1864. *THORP, WILLIAM, B.Sc., F.C.S. 39 Sandringham-road, Kingsland, London, E.

1871. ‡THORPE, T. E., Ph.D., F.R.S. L. & E., F.C.S., Professor of Chemistry in the Royal School of Mines, South Kensington, London, S.W.

1883. §Threlfall, Henry Singleton. 5 Prince's-street, Southport.

1883. ‡Thresh, John C., D.Sc. The Willows, Buxton.

1868. ‡THUILLIER, General Sir H. E. L., R.A., C.S.I., F.R.S., F.R.G.S. 11 Sussex-gardens, Hyde Park, London, W.

1870. ‡Tichborne, Charles R. C., LL.D., F.C.S., M.R.I.A. Apothecaries' Hall of Ireland, Dublin.

1873. *TIDDEMAN, R. H., M.A., F.G.S. 28 Jermyn-street, London, S.W.

1884. §Tidy, Charles Meymott, M.D. 3 Mandeville-place, Cavendish-square, London, W.

1874. ‡TILDEN, WILLIAM A., D.Sc., F.R.S., F.C.S., Professor of Chemistry and Metallurgy in the Mason Science College, Birmingham. 36 Frederick-road, Birmingham.

Year of Election.

1873. ‡Tilghman, B. C. Philadelphia, U.S.A.
1883. §Tillyard, A. I., M.A. Fordfield, Cambridge.
1883. ‡Tillyard, Mrs. Fordfield, Cambridge.
Tinker, Ebenezer. Mealhill, near Huddersfield.
1865. ‡Timmins, Samuel, J.P., F.S.A. Hill Cottage, Fillongley, Coventry.
1876. ‡Todd, Rev. Dr. Tudor Hall, Forest Hill, London, S.E.
1857. ‡Tombe, Rev. Canon. Glenealy, Co. Wicklow.
1856. ‡*Tomes, Robert Fisher. Welford, Stratford-on-Avon.*
1864. *TOMLINSON, CHARLES, F.R.S., F.C.S. 7 North-road, Highgate, London, N.
1865. §Tonks, Edmund, B.C.L. Packwood Grange, Knowle, Warwickshire.
1865. *Tonks, William Henry. The Rookery, Sutton Coldfield.
1873. *Tookey, Charles, F.C.S. Royal School of Mines, Jermyn-street, London, S.W.
1861. *Topham, John, A.I.C.E. High Elms, 265 Mare-street, Hackney London, E.
1872. *TOPLEY, WILLIAM, F.G.S., A.I.C.E. Geological Survey Office Jermyn-street, London, S.W.
1875. §Torr, Charles Hawley. 7 Regent-street, Nottingham.
1884. ‡Torrance, John F. Folly Lake, Nova Scotia, Canada.
1884. *Torrance, Rev. Robert, D.D. Guelph, Ontario, Canada.
1859. ‡Torry, Very Rev. John, Dean of St. Andrews. Coupar Angus, N.B.
Towgood, Edward. St. Neot's, Huntingdonshire.
1873. ‡Townend, W. H. Heaton Hall, Bradford, Yorkshire.
1875. ‡Townsend, Charles. Avenue House, Cotham Park, Bristol.
1883. ‡Townsend, Francis Edward. 19 Aughton-road, Birkdale, Southport.
1861. ‡Townsend, William. Attleborough Hall, near Nuneaton.
1877. ‡Tozer, Henry. Ashburton.
1876. *TRAIL, Professor J. W. H., M.A., M.D., F.L.S. University of Aberdeen, Old Aberdeen.
1883. ‡TRAILL, Dr. Ballylough, Bushmills, Ireland.
1870. ‡TRAILL, WILLIAM A. Giant's Causeway Electric Tramway, Portrush, Ireland.
1883. ‡Traill, Mrs. Portrush, Ireland.
1875. ‡Trapnell, Caleb. Severnleigh, Stoke Bishop.
1868. ‡TRAQUAIR, RAMSAY H., M.D., F.R.S., F.G.S., Keeper of the Natural History Collections, Museum of Science and Art, Edinburgh.
1884. ‡Trechmann, Charles O., Ph.D., F.G.S. Hartlepool.
Tregelles, Nathaniel. Liskeard, Cornwall.
1868. ‡Trehane, John. Exe View Lawn, Exeter.
1869. ‡Trehane, John, jun. Bedford-circus, Exeter.
1870. ‡Trench, Dr. Municipal Offices, Dale-street, Liverpool.
Trench, F. A. Newlands House, Clondalkin, Ireland.
1883. ‡Trendell, Edwin James, J.P. Abbey House, Abingdon, Berks.
1884. ‡Trenham, Norman W. 18 St. Alexis-street, Montreal, Canada.
1884. §Tribe, Paul C. M. 44 West Oneida-street, Oswego, New York, U.S.A.
1879. ‡Trickett, F. W. 12 Old Haymarket, Sheffield.
1877. ‡TRIMEN, HENRY, M.B., F.L.S. British Museum, London, S.W.
1871. ‡TRIMEN, ROLAND, F.R.S., F.L.S., F.Z.S. Colonial Secretary's Office, Cape Town, Cape of Good Hope.
1860. §TRISTRAM, Rev. HENRY BAKER, D.D., LL.D., F.R.S., F.L.S., Canon of Durham. The College, Durham.
1884. *Trotter, Alexander Pelham. 7 Furnival's Inn, London, W.C.
1882. *TROTTER, Rev. COUTTS, M.A. Trinity College, Cambridge.
1885. §Trotter, Coutts. 17 Charlotte-square, Edinburgh.

Year of Election.

1869. ‡Troyte, C. A. W. Huntsham Court, Bampton, Devon.
1885. *Tubby, A. H. Guy's Hospital, London, S.E.
1869. ‡Tucker, Charles. Marlands, Exeter.
1847. *Tuckett, Francis Fox. Frenchay, Bristol.
Tuke, James H. Bancroft, Hitchin.
1871. ‡Tuke, J. Batty, M.D. Cupar, Fifeshire.
1881. ‡*Tully, G. T. 10 West Cliff-terrace, Preston.*
1883. §TUPPER, Sir CHARLES, G.C.M.G., C.B., High Commissioner for Canada. 9 Victoria-chambers, London, S.W.
1854. ‡*Turnbull, James, M.D. 86 Rodney-street, Liverpool.*
1855. ‡Turnbull, John. 37 West George-street, Glasgow.
1871. ‡Turnbull, William, F.R.S.E. Menslaws, Jedburgh, N.B.
1873. *Turner, George. Horton Grange, Bradford, Yorkshire.
1882. §Turner, G. S. 9 Carlton-crescent, Southampton.
1883. ‡Turner, Mrs. G. S. 9 Carlton-crescent, Southampton.
1875. ‡*Turner, Thomas, F.S.S. Ashley House, Kingsdown, Bristol.*
1863. *TURNER, Sir WILLIAM, M.B., F.R.S. L. & E., Professor of Anatomy in the University of Edinburgh. 6 Eton-terrace, Edinburgh.
1883. §Turrell, Miss S. S. High School, Redland-grove, Bristol.
1884. *Tutin, Thomas. 247 Sherwood-street, Nottingham.
1842. Twamley, Charles, F.G.S. Ryton-on-Dunsmore, Coventry.
1884. *Tweddell, Ralph Hart. Provender, Faversham, Kent.
1847. ‡TWISS, Sir TRAVERS, Q.C., D.C.L., F.R.S., F.R.G.S. 3 Paper-buildings, Temple, London, E.C.
1882. §Tyer, Edward. Horneck, Fitzjohn's-avenue, Hampstead, London, N.W.
1865. ‡TYLOR, EDWARD BURNETT, D.C.L., LL.D., F.R.S., Keeper of the University Museum, Oxford.
1858. *TYNDALL, JOHN, D.C.L., LL.D., Ph.D., F.R.S., F.G.S., Professor of Natural Philosophy in the Royal Institution. Royal Institution, Albemarle-street, London, W.
1883. ‡Tyrer, Thomas, F.C.S. Garden-wharf, Battersea, London, S.W.
1861. *Tysoe, John. 28 Heald-road, Bowdon, near Manchester.

1884. *Underhill, G. E., M.A. Magdalen College, Oxford.
1885. §Unwin, Howard. Newton-grove, Bedford Park, Chiswick, London.
1883. §Unwin, John. Park-crescent, Southport.
1883. §Unwin, William Andrews. The Briars, Freshfield, near Liverpool.
1876. *UNWIN, W. C., M.Inst.C.E., Professor of Hydraulic Engineering. 7 Palace-gate Mansions, Kensington, London, W.
1872. ‡Upward, Alfred. 11 Great Queen-street, Westminster, London, S.W.
1876. ‡Ure, John F. 6 Claremont-terrace, Glasgow.
1859. ‡Urquhart, W. Pollard. Craigston Castle, N.B.; and Castlepollard, Ireland.
1866. ‡Urquhart, William W. Rosebay, Broughty Ferry, by Dundee.
1880. ‡USSHER, W. A. E., F.G.S. 28 Jermyn-street, London, S.W.

1885. §Vachell, Charles Tanfield, M.D. Cardiff.
1863. ‡Vandoni, le Commandeur Comte de, Chargé d'Affaires de S. M. Tunisienne, Geneva.
1884. ‡Van Horne, W. C. Dorchester-street West, Montreal, Canada.
1883. *VanSittart, The Hon. Mrs. A. A. 11 Lypiatt-terrace, Cheltenham.
1868. ‡Varley, Frederick H., F.R.A.S. Mildmay Park Works, Mildmay-avenue, Stoke Newington, London, N.
1865. *VARLEY, S. ALFRED. 2 Hamilton-road, Highbury Park, London, N.

Year of Election.

1870. ‡Varley, Mrs. S. A. 2 Hamilton-road, Highbury Park, London, N.
1869. ‡Varwell, P. Alphington-street, Exeter.
1884. §Vasey, Charles. 112 Cambridge-gardens, London, W.
1875. ‡Vaughan, Miss. Burlton Hall, Shrewsbury.
1883. ‡Vaughan, William. 42 Sussex-road, Southport.
1881. §Veley, V. H., M.A., F.C.S. University College, Oxford.
1873. *Verney, Captain Edmund H., R.N., F.R.G.S. Rhianva, Bangor, North Wales.
1883. *Verney, Mrs. Rhianva, Bangor, North Wales.
Verney, Sir Harry, Bart., M.P. Lower Claydon, Buckinghamshire.
Vernon, George John, Lord. Sudbury Hall, Derbyshire.
1883. ‡Vernon, H. H., M.D. York-road, Birkdale, Southport.
1879. ‡Veth, D. D. Leiden, Holland.
1864. *Vicary, William, F.G.S. The Priory, Colleton-crescent, Exeter.
1868. ‡Vincent, Rev. William. Postwick Rectory, near Norwich.
1883. ‡Vines, Sydney Howard, M.A., D.Sc., F.R.S., F.L.S. 66 Hills-road, Cambridge.
1856. ‡Vivian, Edward, M.A. Woodfield, Torquay.
*Vivian, Sir H. Hussey, Bart., M.P., F.G.S. Park Wern, Swansea; and 27 Belgrave-square, London, S.W.
1884. ‡Von Linden, François Hermann. Amsterdam, Holland.
1869. ‡Vose, Dr. James. Gambier-terrace, Liverpool.

1860. §Waddingham, John. Guiting Grange, Winchcombe, Gloucestershire.
1884. ‡Wait, Charles E. Rolla, Missouri, U.S.A.
1879. *Wake, Bernard. Abbeyfield, Sheffield.
1870. §Wake, Charles Staniland. Welton, near Brough, East Yorkshire.
1884. ‡Waldstein, Charles, M.A., Ph.D., Director of the Fitzwilliam Museum, Cambridge. Cambridge.
1873. ‡Wales, James. 4 Mount Royd, Manningham, Bradford, Yorkshire.
1882. *Walkden, Samuel. (Care of Messrs. Guillaume & Sons, 9 Salisbury-square, Fleet-street, London, E.C.)
1885. §Walker, Baillie. 52 Victoria-street, Aberdeen.
1885. §Walker, Charles Clement, F.R.A.S. Lillieshall Old Hall, Newport, Shropshire.
1883. ‡Walker, E. R. Pagefield Ironworks, Wigan.
Walker, Frederick John. The Priory, Bathwick, Bath.
1883. ‡Walker, George. 11 Hamilton-square, Birkenhead, Liverpool.
1866. ‡Walker, H. Westwood, Newport, by Dundee.
1885. §Walker, General J. T., C.B., R.E., LL.D., F.R.S., F.R.G.S. 13 Cromwell-road, London, S.W.
1866. *Walker, John Francis, M.A., F.C.S., F.G.S., F.L.S. 16 Gillygate, York.
1881. ‡Walker, John Sydenham. 83 Bootham, York.
1867. *Walker, Peter G. 2 Airlie-place, Dundee.
1866. ‡Walker, S. D. 38 Hampden-street, Nottingham.
1884. ‡Walker, Samuel. Woodbury, Sydenham Hill, London, S.E.
1883. ‡Walker, Thomas A. 4 Saunders-street, Southport.
Walker, William. 47 Northumberland-street, Edinburgh.
1881. *Walker, William. 14 Bootham-terrace, York.
1883. §Walker, Mrs. 14 Bootham-terrace, York.
1883. ‡Wall, Henry. 14 Park-road, Southport.
1863. ‡Wallace, Alfred Russel, F.L.S., F.R.G.S. Nutwood Cottage, Frith Hill, Godalming.

Year of Election.

1883. §Wallace, George J. Hawthornbank, Dunfermline.
1859. ‡WALLACE, WILLIAM, Ph.D., F.C.S. Chemical Laboratory, 138 Bath-street, Glasgow.
1862. ‡Wallich, George Charles, M.D., F.L.S., F.R.G.S. 26 Addison-road North, Notting Hill, London, W.
1883. ‡Wallis, Rev. Frederick. Caius College, Cambridge.
1884. §Wallis, Herbert. Redpath-street, Montreal, Canada.
1883. ‡Walmesley, Oswald. Shevington Hall, near Wigan.
1883. ‡Walmsley, T. M. Clevelands, Chorley-road, Heaton, Bolton.
1862. ‡WALPOLE, The Right Hon. SPENCER HORATIO, M.A., D.C.L., F.R.S. Ealing, Middlesex, W.
1863. ‡Walters, Robert. Eldon-square, Newcastle-on-Tyne.
1881. ‡Walton, Thomas, M.A. Oliver's Mount School, Scarborough.
Walton, Thomas Todd. Mortimer House, Clifton, Bristol.
1863. ‡Wanklyn, James Alfred. 7 Westminster-chambers, London, S.W.
1884. §Wanless, John, M.D. 88 Union-avenue, Montreal, Canada.
1872. ‡Warburton, Benjamin. Leicester.
1874. §Ward, F. D., J.P., M.R.I.A. Clonaver, Strandtown, Co. Down.
1881. §Ward, George, F.C.S. Buckingham-terrace, Headingley, Leeds.
1879. ‡Ward, H. Marshall, M.A., Professor of Botany in the Royal Indian Civil Engineering College, Cooper's Hill, Egham.
1874. ‡Ward, John, F.S.A., F.G.S., F.R.G.S. Lenoxvale, Belfast.
1857. ‡Ward, John S. Prospect Hill, Lisburn, Ireland.
1880. *Ward, J. Wesney. 5 Holtham-road, St. John's Wood, London, N.W.
1884. *Ward, John William. Newstead, Halifax.
1883. ‡Ward, Thomas, F.C.S. Arnold House, Blackpool.
1882. ‡Ward, William. Cleveland Cottage, Hill-lane Southampton.
*Ward, William Sykes, F.C.S. 12 Bank-street, and Denison Hall, Leeds.
1867. ‡Warden, Alexander J. 23 Panmure-street, Dundee.
1858. ‡Wardle, Thomas. Leek Brook, Leek, Staffordshire.
1884. ‡Wardwell, George J. Rutland, Vermont, U.S.A.
1865. ‡Waring, Edward John, M.D., F.L.S. 49 Clifton-gardens, Maida Vale, London, W.
1878. §WARINGTON, ROBERT, F.C.S. Harpenden, St. Albans, Herts.
1882. ‡Warner, F. W., F.L.S. 20 Hyde-street, Winchester.
1884. *Warner, James D. 199 Baltic-street, Brooklyn, U.S.A.
1875. ‡Warren, Algernon. Naseby House, Pembroke-road, Clifton, Bristol.
1883. *Warren, Dr. Samuel. Abberley Villa, Hoylake.
1856. ‡Washbourne, Buchanan, M.D. Gloucester.
1876. ‡Waterhouse, A. Willenhall House, Barnet, Herts.
1875. *Waterhouse, Major J. 1 Wood-street, Calcutta. (Care of Messrs. Trübner & Co., Ludgate-hill, London, E.C.)
1854. ‡Waterhouse, Nicholas. 5 Rake-lane, Liverpool.
1870. ‡Waters, A. T. H., M.D. 29 Hope-street, Liverpool.
1875. ‡Waters, Arthur W., F.G.S., F.L.S. Woodbrook, Alderley Edge, near Manchester.
1875. ‡Watherston, Rev. Alexander Law, M.A., F.R.A.S. The Grammar School, Hinckley, Leicestershire.
1881. §Watherston, E. J. 12 Pall Mall East, London, S.W.
1884. ‡Watson, A. G., D.C.L. The School, Harrow, Middlesex.
1867. ‡Watson, Rev. Archibald, D.D. The Manse, Dundee.
1883. ‡Watson, C. Knight, M.A. Society of Antiquaries, Burlington House, London, W.
1855. ‡Watson, Ebenezer. 1 Woodside-terrace, Glasgow.
1867. ‡Watson, Frederick Edwin. Thickthorne House, Cringleford, Norwich

Year of Election.

1885. §Watson, Brigade Surgeon G.A. East India United Service Club, St. James's-square, London, S.W.

*WATSON, HENRY HOUGH, F.C.S. 227 The Folds, Bolton-le-Moors.

1882. §WATSON, Rev. H. W., D.Sc., F.R.S. Berkeswell Rectory, Coventry.

1873. *Watson, Sir James. 9 Woodside-terrace, Glasgow.

1884. ‡Watson, John. Queen's University, Kingston, Ontario, Canada.

1859. ‡WATSON, JOHN FORBES, M.A., M.D., F.L.S. India Museum, London, S.W.

1863. ‡Watson, Joseph. Bensham-grove, near Gateshead-on-Tyne.

1863. ‡Watson, R. S. 101 Pilgrim-street, Newcastle-on-Tyne.

1867. ‡Watson, Thomas Donald. 41 Cross-street, Finsbury, London, E.C.

1879. *WATSON, WILLIAM HENRY, F.C.S., F.G.S. Analytical Laboratory, The Folds, Bolton-le-Moors.

1882. ‡Watt, Alexander. 89 Hartington-road, Sefton Park, Liverpool.

1884. ‡Watt, D. A. P. 284 Upper Stanley-street, Montreal, Canada.

1869. ‡Watt, Robert B. E., F.R.G.S. Ashley-avenue, Belfast.

1861. ‡Watts, Sir James. Abney Hall, Cheadle, near Manchester.

1875. *WATTS, JOHN, B.A., D.Sc. Merton College, Oxford.

1884. *Watts, Rev. Robert R. Stourpaine Vicarage, Blandford.

1870. §Watts, William, F.G.S. Oldham Corporation Waterworks, Piethorn, near Rochdale.

1873. *WATTS, W. MARSHALL, D.Sc. Giggleswick Grammar School, near Settle.

1883. §Watts, W. W., B.A., F.G.S. Broseley, Shropshire.

Waud, Rev. S. W., M.A., F.R.A.S., F.C.P.S. Rettenden, near Wickford, Essex.

1859. ‡*Waugh, Edwin. Sager-street, Manchester.*

1869. ‡Way, Samuel James. Adelaide, South Australia.

1883. ‡Webb, George. 5 Tenterden-street, Bury, Lancashire.

1871. ‡Webb, Richard M. 72 Grand-parade, Brighton.

1866. *WEBB, WILLIAM FREDERICK, F.G.S., F.R.G.S. Newstead Abbey, near Nottingham.

1859. ‡Webster, John. Edgehill, Aberdeen.

1834. ‡Webster, Richard, F.R.A.S. 6 Queen Victoria-street, London, E.C.

1882. *Webster, Sir Richard Everard, Q.C., M.P. Hornton Lodge, Hornton-street, Kensington, London, S.W.

1884. *Wedekind, Dr. Ludwig, Professor of Mathematics at Karlsruhe. Karlsruhe.

1854. ‡Weightman, William Henry. Fern Lea, Seaforth, Liverpool.

1865. ‡Welch, Christopher, M.A. United University Club, Pall Mall East, London, S.W.

1876. ‡Weldon, W. F. R., B.A. St. John's College, Cambridge.

1881. §Wellcome, Henry S. First Avenue Hotel, Holborn, London, W.C.

1879. §Wells, Charles A. Lewes; and 45 Springfield-road, Brighton.

1881. §Wells, Rev. Edward, B.A. 21 Buckland-crescent, South Hampstead, London, N.W.

1883. ‡Wells, G. I. J. Cressington Park, Liverpool.

1883. §Welsh, Miss. Girton College, Cambridge.

1850. ‡Wemyss, Alexander Watson, M.D. St. Andrews, N.B.

1881. *Wenlock, The Right Hon. Lord. 8 Great Cumberland-place, London, W.; and Escrick Park, Yorkshire.

Wentworth, Frederick W. T. Vernon. Wentworth Castle, near Barnsley, Yorkshire.

1864. *Were, Anthony Berwick. Hensingham, Whitehaven, Cumberland.

1865. ‡Wesley, William Henry. Royal Astronomical Society, Burlington House, London, W.

1853. ‡West, Alfred. Holderness-road, Hull.

Year of Election.

1870. ‡West, Captain E. W. Bombay.
1853. ‡West, Leonard. Summergangs Cottage, Hull.
1853. ‡West, Stephen. Hessle Grange, near Hull.
1870. *Westgarth, William. 10 Bolton-gardens, South Kensington, London, S.W.
1842. Westhead, Edward. Chorlton-on-Medlock, near Manchester.
1882. §Westlake, Ernest, F.G.S. Fordingbridge, Hants.
1882. ‡Westlake, Richard. Portswood, Southampton.
1882. ‡Westlake, W. C. Grosvenor House, Southampton.
1857. *Westley, William. 24 Regent-street, London, S.W.
1863. ‡Westmacott, Percy. Whickham, Gateshead, Durham.
1875. *Weston, Joseph D. Dorset House, Clifton Down, Bristol.
1864. ‡WESTROPP, W. H. S., M.R.I.A. Lisdoonvarna, Co. Clare.
1860. ‡WESTWOOD, JOHN O., M.A., F.L.S., Professor of Zoology in the University of Oxford. Oxford.
1882. §WETHERED, EDWARD, F.G.S. 5 Berkeley-place, Cheltenham.
1884. ‡Wharton, E. R., M.A. 4 Broad-street, Oxford.
1885. *Wharton, Captain W. J. L., R.N., F.R.G.S. Broadheath, Wimbledon Common, Surrey.
1853. ‡Wheatley, E. B. Cote Wall, Mirfield, Yorkshire.
1866. ‡Wheatstone, Charles C. 19 Park-crescent, Regent's Park, London, N.W.
1884. §Wheeler, Claude L. 123 Metcalfe-street, Montreal, Canada.
1847. ‡Wheeler, Edmund, F.R.A.S. 48 Tollington-road, Holloway, London, N.
1883. *Wheeler, George Brash. Elm Lodge, Wickham-road, Beckenham, Kent.
1878. *Wheeler, W. H., M.Inst.C.E. Boston, Lincolnshire.
1883. §Whelpton, Miss K. Newnham College, Cambridge.
1879. *WHIDBORNE, Rev. GEORGE FERRIS, M.A., F.G.S. Charante, Torquay.
1873. ‡Whipple, George Matthew, B.Sc., F.R.A.S. Kew Observatory, Richmond, Surrey.
1884. ‡Whischer, Arthur Henry. Dominion Lands Office, Winnipeg, Canada.
1874. ‡Whitaker, Henry, M.D. 33 High-street, Belfast.
1883. ‡Whitaker, T. Helm View, Halifax.
1859. *WHITAKER, WILLIAM, B.A., F.G.S. Geological Survey Office, Jermyn-street, London, S.W.; and 33 East Park-terrace, Southampton.
1876. ‡White, Angus. Easdale, Argyleshire.
1883. ‡White, Charles. 23 Alexandra-road, Southport.
1882. §White, Rev. George Cecil, M.A. St. Paul's Vicarage, Southampton.
1885. *White, J. Martin. Spring Grove, Dundee.
1876. *White, James. Overtoun, Dumbarton.
1873. ‡White, John. Medina Docks, Cowes, Isle of Wight.
1859. ‡WHITE, JOHN FORBES. 311 Union-street, Aberdeen.
1883. ‡White, John Reed. Rossall School, near Fleetwood.
1865. ‡White, Joseph. Regent's-street, Nottingham.
1869. ‡White, Laban. Blandford, Dorset.
1884. ‡White, R. 'Gazette' Office, Montreal, Canada.
1859. ‡White, Thomas Henry. Tandragee, Ireland.
1877. *White, William. 365 Euston-road, London, N.W.
1883. *White, Mrs. 365 Euston-road, London, N.W.
1861. ‡Whitehead, James, M.D. 87 Mosley-street, Manchester.
1861. *Whitehead, John B. Ashday Lea, Rawtenstall, Manchester.
1861. *Whitehead, Peter Ormerod. 25 Peel-avenue, Ardwick, Manchester.
1883. ‡Whitehead, P. J. 6 Cross-street, Southport.

Year of Election.

1855. *Whitehouse, Wildeman W. O. 18 Salisbury-road, West Brighton.
1871. ‡Whitelaw, Alexander. 1 Oakley-terrace, Glasgow.
1884. ‡Whiteley, Joseph. Huddersfield.
1881. §Whitfield, John, F.C.S. 113 Westborough, Scarborough.
1866. ‡Whitfield, Samuel. Eversfield, Eastnor-grove, Leamington.
1852. ‡Whitla, Valentine. Beneden, Belfast.
Whitley, Rev. Charles Thomas, M.A., F.R.A.S. Bedlington, Morpeth.
1870. ‡Whittem, James Sibley. Walgrave, near Coventry.
1857. *WHITTY, Rev. JOHN IRWINE, M.A., D.C.L., LL.D. 92 Mortimer-street, Herne Bay, Kent.
1874. *Whitwill, Mark. Redland House, Bristol.
1883. ‡Whitworth, James. 88 Portland-street, Southport.
*WHITWORTH, Sir JOSEPH, Bart., LL.D., D.C.L., F.R.S. Stancliffe, Matlock, Derbyshire.
1870. ‡WHITWORTH, Rev. W. ALLEN, M.A. Glenthorne-road, Hammersmith, London, W.
1865. ‡Wiggin, Henry. Metchley Grange, Harborne, Birmingham.
1885. §Wigglesworth, Alfred. Gordondale House, Aberdeen.
1881. *Wigglesworth, James. New Parks House, Falsgrave, Scarborough.
1883. ‡Wigglesworth, Mrs. New Parks House, Falsgrave, Scarborough.
1881. *Wigglesworth, Robert. Buckingham Works, York.
1878. ‡Wigham, John R. Albany House, Monkstown, Dublin.
1883. ‡Wigner, G. W., F.C.S. Plough-court, 37 Lombard-street, London, E.C.
1884. ‡Wilber, Charles Dana, LL.D. Grand Pacific Hotel, Chicago, U.S.A.
1881. ‡WILBERFORCE, W. W. Fishergate, York.
1857. ‡Wilkinson, George. Temple Hill, Killiney, Co. Dublin.
1879. ‡Wilkinson, Joseph. York.
1859. ‡WILKINSON, ROBERT. Lincoln Lodge, Totteridge, Hertfordshire.
1872. ‡Wilkinson, William. 168 North-street, Brighton.
1869. §Wilks, George Augustus Frederick, M.D. Stanbury, Torquay.
1859. ‡Willet, John, M.Inst.C.E. 35 Albyn-place, Aberdeen.
1872. ‡WILLETT, HENRY, F.G.S. Arnold House, Brighton.
WILLIAMS, CHARLES JAMES B., M.D., F.R.S. 47 Upper Brook-street, Grosvenor-square, London, W.
1861. *Williams, Charles Theodore, M.A., M.B. 47 Upper Brook-street, Grosvenor-square, London, W.
1883. *Williams, Edward Starbuck. Ty-ar-y-graig, Swansea.
1861. *Williams, Harry Samuel, M.A., F.R.A.S. 1 Gorse-lane, Swansea.
1875. *Williams, Herbert A., M.A. 91 Pembroke-road, Clifton, Bristol.
1883. ‡Williams, Rev. H. A. The Ridgeway, Wimbledon, Surrey.
1857. ‡Williams, Rev. James. Llanfairinghornwy, Holyhead.
1870. §WILLIAMS, JOHN, F.C.S. 63 Warwick Gardens, Kensington, London, W.
1875. *Williams, M. B. Killay House, near Swansea.
1879. ‡WILLIAMS, MATTHEW W., F.C.S. Sterndale House, Sterndale-road, Brook Green, London, W.
Williams, Robert, M.A. Bridehead, Dorset.
1883. ‡Williams, R. Price. North Brow, Primrose Hill, London, N.W.
1869. ‡WILLIAMS, Rev. STEPHEN. Stonyhurst College, Whalley, Blackburn.
1883. §Williams, T. H. 2 Chapel-walk, South Castle-street, Liverpool.
1883. §Williams, T. Howell. 125 Fortess-road, London, N.W.
1877. *Williams, W. Carleton, F.C.S. Firth College, Sheffield.
1865. ‡Williams, W. M. Stonebridge Park, Willesden.
1883. §Williamson, Miss. Sunnybank, Ripon, Yorkshire.

Year of Election.

1850. *WILLIAMSON, ALEXANDER WILLIAM, Ph.D., LL.D., For. Sec. R.S., F.C.S., Corresponding Member of the French Academy, Professor of Chemistry and of Practical Chemistry, University College, London. (GENERAL TREASURER.) University College, London, W.C.

1857. ‡WILLIAMSON, BENJAMIN, M.A., F.R.S., Professor of Natural Philosophy in the University of Dublin. Trinity College, Dublin.

1876. ‡Williamson, Rev. F. J. Ballantrae, Girvan, N.B.

1863. ‡Williamson, John. South Shields.

1876. ‡Williamson, Stephen. 19 James-street, Liverpool.

WILLIAMSON, WILLIAM C., LL.D., F.R.S., Professor of Botany in Owens College, Manchester. 4 Egerton-road, Fallowfield, Manchester.

1883. ‡WILLIS, T. W. 51 Stanley-street, Southport.

1882. ‡Willmore, Charles. Queenwood College, near Stockbridge, Hants.

1865. *Willmott, Henry. Hatherley Lawn, Cheltenham.

1859. *Wills, The Hon. Sir Alfred. 12 King's Bench-walk, Inner Temple, London, E.C.

1885. §Wilson, Alexander H. 2 Albyn-place, Aberdeen.

1878. ‡Wilson, Professor Alexander S., M.A., B.Sc. 124 Bothwell-street, Glasgow.

1859. ‡Wilson, Alexander Stephen, C.E. North Kinmundy, Summerhill, by Aberdeen.

1876. ‡Wilson, Dr. Andrew. 118 Gilmore-place, Edinburgh.

1874. ‡WILSON, Colonel Sir C. W., R.E., K.C.B., K.C.M.G., D.C.L., F.R.S., F.R.G.S. Mountjoy Barracks, Phœnix Park, Dublin.

1850. ‡Wilson, Dr. Daniel. Toronto, Upper Canada.

1876. ‡Wilson, David. 124 Bothwell-street, Glasgow.

1863. ‡Wilson, Frederic R. Alnwick, Northumberland.

1847. *Wilson, Frederick. 73 Newman-street, Oxford-street, London, W.

1885. §Wilson, Brigade-Surgeon, G. A. East India United Service Club, St. James's-square, London, S.W.

1875. ‡Wilson, George Fergusson, F.R.S., F.C.S., F.L.S. Heatherbank, Weybridge Heath, Surrey.

1874. *Wilson, George Orr. Dunardagh, Blackrock, Co. Dublin.

1863. ‡Wilson, George W. Heron Hill, Hawick, N.B.

1883. *Wilson, Henry, M.A. Eastnor, Malvern Link, Worcestershire.

1879. ‡Wilson, Henry J. 255 Pitsmoor-road, Sheffield.

1885. §Wilson, J. Dove, LL.D. 17 Rubislaw-terrace, Aberdeen.

1857. ‡Wilson, James Moncrieff. Queen Insurance Company, Liverpool.

1865. ‡WILSON, Rev. JAMES M., M.A., F.G.S. The College, Clifton, Bristol.

1884. ‡Wilson, James S. Grant. H.M. Geological Survey, Sheriff Court-buildings, Edinburgh.

1858. *Wilson, John. Seacroft Hall, near Leeds.

WILSON, JOHN, F.R.S.E., F.G.S., Professor of Agriculture in the University of Edinburgh. The University, Edinburgh.

1879. ‡Wilson, John Wycliffe. Eastbourne, East Bank-road, Sheffield.

1876. ‡Wilson, R. W. R. St. Stephen's Club, Westminster, S.W.

1847. *Wilson, Rev. Sumner. Preston Candover Vicarage, Basingstoke.

1883. ‡Wilson, T. Rivers Lodge, Harpenden, Hertfordshire.

1867. ‡Wilson, Rev. William. Free St. Paul's, Dundee.

1871. *Wilson, William E. Daramona House, Rathowen, Ireland.

1861. *WILTSHIRE, Rev. THOMAS, M.A., F.G.S., F.L.S., F.R.A.S., Assistant Professor of Geology and Mineralogy in King's College, London. 25 Granville-park, Lewisham, London, S.E.

1877. ‡Windeatt, T. W. Dart View, Totnes.

Year of Election.

1854. *Winfield, Edward Higgin. Edelstowe, Bromley Park, Bromley, Kent.
1863. *WINWOOD, Rev. H. H., M.A., F.G.S. 11 Cavendish-crescent, Bath.
1883. §Wolfenden, Samuel. Cowley Hill, St. Helen's, Lancashire.
1884. ‡Womack, Frederick, Lecturer on Physics and Applied Mathematics at St. Bartholomew's Hospital. 68 Abbey-road, London, N.W.
1881. *Wood, Alfred John. 5 Cambridge-gardens, Richmond, Surrey.
1883. §Wood, Mrs. A. J. 5 Cambridge-gardens, Richmond, Surrey.
1863. *Wood, Collingwood L. Freeland, Forgandenny, N.B.
1861. *Wood, Edward T. Blackhurst, Brinscall, Chorley, Lancashire.
1883. ‡Wood, Miss Emily F. Egerton Lodge, near Bolton, Lancashire.
*Wood, George B., M.D. 1117 Arch-street, Philadelphia, United States.
1875. *Wood, George William Rayner. Singleton, Manchester.
1878. §WOOD, H. TRUEMAN, M.A. Society of Arts, John-street, Adelphi, London, W.C.
1883. *WOOD, JAMES, LL.D. Woodbank, Mornington-road, Southport.
1881. §Wood, John, B.A., F.R.A.S. Wharfedale College, Boston Spa, Yorkshire.
1883. *Wood, J. H. Woodbine Lodge, Scarisbrick New-road, Southport.
1883. §Wood, Mrs. Mary. Ellison-place, Newcastle-on-Tyne.
1883. ‡Wood, P. F. Ardwick Lodge, Park-avenue, Southport.
1864. ‡Wood, Richard, M.D. Driffield, Yorkshire.
1871. ‡Wood, Provost T. Barleyfield, Portobello, Edinburgh.
1850. ‡Wood, Rev. Walter. Elie, Fife.
Wood, William. Edge-lane, Liverpool.
1865. *Wood, William, M.D. 99 Harley-street, London, W.
1872. §Wood, William Robert. Carlisle House, Brighton.
*Wood, Rev. William Spicer, M.A., D.D. Higham, Rochester.
1863. *WOODALL, JOHN WOODALL, M.A., F.G.S. St. Nicholas House, Scarborough.
1870. ‡Woodburn, Thomas. Rock Ferry, Liverpool.
1884. ‡Woodbury, C. J. H. 31 Devonshire-street, Boston, U.S.A.
1883. ‡Woodcock, Herbert S. The Elms, Wigan.
1884. ‡Woodcock T., B.A. The Old Hall School, Wellington, Shropshire.
1884. ‡Woodd, Arthur B. Woodlands, Hampstead, London, N.W.
1850. *Woodd, Charles H. L., F.G.S. Roslyn House, Hampstead, London, N.W.
1865. ‡Woodhill, J. C. Pakenham House, Charlotte-road, Edgbaston, Birmingham.
1871. ‡Woodiwis, James. 51 Back George-street, Manchester.
1872. ‡Woodman, James. 26 Albany-villas, Hove, Sussex.
1869. ‡Woodman, William Robert, M.D. Ford House, Exeter.
*WOODS, EDWARD, M.Inst.C.E. 6B Victoria-street, Westminster, London, S.W.
1883. ‡Woods, Dr. G. A., F.R.S.E., F.R.M.S. Carlton House, 57 Hoghton-street, Southport.
WOODS, SAMUEL. 1 Drapers'-gardens, Throgmorton-street, London, E.C.
*WOODWARD, C. J., B.Sc. 97 Harborne-road, Birmingham.
1866. ‡WOODWARD, HENRY, LL.D., F.R.S., F.G.S., Keeper of the Department of Geology, British Museum (Natural History), Cromwell-road, London, S.W.
1870. ‡WOODWARD, HORACE B., F.G.S. Geological Museum, Jermyn-street, London, S.W.
1881. §Wooler, W. A. Sadberge Hall, Darlington.

Year of Election.

1884. *Woolcock, Henry. Rickerby House, St. Bees.
1877. ‡Woollcombe, Robert W. 14 Acre-place, Stoke, Devonport.
1883. *Woolley, George Stephen. 69 Market-street, Manchester.
1856. ‡Woolley, Thomas Smith, jun. South Collingham, Newark.
WORCESTER, The Right Rev. HENRY PHILPOTT, D.D., Lord Bishop of. Hartlebury Castle, Kidderminster.
1874. ‡Workman, Charles. Ceara, Windsor, Belfast.
1878. ‡Wormell, Richard, M.A., D.Sc. Roydon, near Ware, Hertfordshire.
1863. *Worsley, Philip J. Rodney Lodge, Clifton, Bristol.
1855. *Worthington, Rev. Alfred William, B.A. Stourbridge, Worcestershire.
Worthington, Archibald. Whitchurch, Salop.
Worthington, James. Sale Hall, Ashton-on-Mersey.
1856. ‡Worthy, George S. 2 Arlington-terrace, Mornington-crescent, Hampstead-road, London, N.W.
1884. ‡Wragge, Edmund. 109 Wellesley-street, Toronto, Canada.
1879. §Wrentmore, Francis, 34 Holland Villas-road, Kensington, London, S.W.
1883. *Wright, Rev. Arthur, M.A. Queen's College, Cambridge.
1883. *Wright, Rev. Benjamin, M.A. The Rectory, Darlaston.
1871. §WRIGHT, C. R. A., D.Sc., F.R.S., F.C.S., Lecturer on Chemistry in St. Mary's Hospital Medical School, Paddington, London, W.
1861. *Wright, E. Abbot. Castle Park, Frodsham, Cheshire.
1857. ‡WRIGHT, E. PERCEVAL, M.A., M.D., F.L.S., M.R.I.A., Professor of Botany, and Director of the Museum, Dublin University. 5 Trinity College, Dublin.
1884. ‡Wright, Harrison. Wilkes' Barré, Pennsylvania, U.S.A.
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